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A Review of the Effect of Deficit Irrigation and Mulching on Yield and Water Productivity of Drip Irrigated Onion

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Abstract: ***Water is the most important substrate of the photosynthesis process and its scarcity directly limits growth of plants hence agricultural production. In a water limiting scenario, water productivity is maximized whereas incomes are optimized. Water productivity and Onion yields therefore, needs to beassessed through integrated practice of drip irrigation, deficit irrigationanduse of mulches to determine the level of production at which income is optimized. Deficit irrigation involves exposing plants to certain levels of water stress during either a particular growth period or throughout the whole growth season. The optimum level of production can only be obtained by conducting an economic analysis of cost-benefit ratio of input and output.***

Keywords: Deficit irrigation, Water productivity, Evapotranspiration

1. Introduction

The growing global demand for food and other agricultural products requires urgent measures to raise water use productivity to curb imminent scarcity.

Kirda *et al*., (2020), observed that Irrigated agriculture was the major consumer of water globally, estimated at 70% of withdrawals and providing 35-40% of all crop production. They projected that by 2050, the world water requirement for agriculture will have increased by 19% due to irrigation needs. Due to scarce water resources for agriculture, deficit irrigation (DI) has been developed to raise the efficient and economical use of water for agricultural production at the farm level. It is a water application strategy that can be used with different methods of irrigation application. Research indicates that it limits water applications to drought-sensitive growth stages with the aim of increasing water productivity and optimizing yields (Geerts *et al*., 2009).The saved water can be utilized for irrigating extra land area and for other uses (Kipkorir *et al*. 2001). The accurate application of DI prevents loss of nutrients through leaching at the root zone, thereby resulting in enhanced quality of groundwater (Ünlü*et al*., 2006) and improved fertilizer utilization (Pandey *et al*., 2000). However, the DI can only be applied by users with accurate knowledge of crop sensitivity to water stress and the economic impact on yield reduction (English M., 1990).

Onion**,** (*Allium cepa*), being the oldest known herbaceous biennial, cross-pollinated and cool season vegetable crop in the family *Amaryllidaceae*, is grown for its edible bulb. The Onion is believed to have originated from southwestern Asia and is now widely grown in the world, mainly in the temperate regions. Onions are mainly used in cooking to add flavour, colour and texture to a variety of dishes and cuisines; hence its demand remains high throughout the year.

Onion is a crop whose roots mostly occupy the upper 30 cm of soil with a few roots reaching 60 cm deep. The crop grows well under a wide range of climatic conditions without the extremes of cold and heat and excessive rainfall, though for optimum development, the crop requires a daily mean temperature of between 15^{o} C and 25^{o}C before bulbing and 25^{o}C and 35^{o} C for bulb development. It requires relative humidity of about 70% for good growth. Bulb Onions are influenced by the length of days and nights, andrequires 350 to 550 mm of water for optimum yield. The crop is less sensitive to water deficit during vegetative growth period and late season stage.

Onion grows well in medium textured and well drained soils with good water holding capacity and adequate organic matter. For maximum yield, loamy soil is most suitable. The optimum pH range is 6 to 7.5. Onion crop is more sensitive to very acidic, saline and alkaline soils and water-logging conditions.

Onion is considered as one of the commercial vegetable crops grown and utilized in most parts of the world. China is leading in production followed by India, Egypt and the USA, each producing 23.9, 19.4, 3.11 and 3.0 million MT annually, respectively. Production of Onion in India in 2018 was 22million MT, 12% higher than the production achieved in the previous 5 years. The leading state in production of Onion is Maharashtra followed by Madhya Pradesh which produced in the same year 3.856 million MT, accounting for 18% of total output of Onion in the country, from more than 1,164,300 ha, with productivity of 17 MT/ha (Horticulture Statistics 2018).

Deficit Irrigation

Deficit irrigation involves exposing plants to certain levels of water stress during either a particular growth period or throughout the whole growth season. It ensures optimum and sustainable agricultural production in a given region, and maximizes incomes of the farmers if irrigation water resources are limited or expensive (Stegman *et al., 1990).*

Yield Response to Deficit Irrigation

Bhagyawant *et al*. (2015) studied yield response factor (Ky) for onion during summer season of 2012 and 2013 under deficit irrigation and ascertained that the seasonal Ky was 1.58, 1.48 and 1.54 during the seasons of 2012, 2013 and the mean of both 2012 and 2013 respectively. Ky indicated a linear relationship between the decrease in relative water consumption and the decrease in relative yield. The Onion yields were higher with less water stress and decreased with increase in water stress showing the response of yield with respect to the decrease in water consumption, thus explaining the decrease in yield due to per unit decrease in water consumption.

Abdelsattar *et al.*, (2019) conducted a research to evaluate the response of onion growth, plant water status, bulb yield, irrigation water use efficiency and bulb quality using two levels of deficit irrigation treatments and a control by applying, 50, 75, and 100% of the irrigation water requirements during three different seasons. It was observed that the computed yield response factor of 0.71 indicated a crop which was tolerant to water stress due to deficit water application.

Stewart *et al.*, (1977) indicated that Crop yields obtained under various DI levels when fitted to the linear crop yield response functions, showed that cotton, maize, wheat, sunflower, sugar beet and potato were well suited to DI practices imposed throughout the growing season. The crops also included common bean, sugar cane groundnut and soybean where reduced evapotranspiration was limited to certain growth stage(s). With DI of 25 percent, WUE was found to be 1.2 times of that which was achieved under normal irrigation practices. Irrigation scheduling based on DI, demands careful evaluation to ensure that the increasingly scarce supplies of irrigation water resource is efficiently utilized.

Crop Water Productivity

Kumar *et al*., (2008) stated that the term crop water productivity is used in literature as physical water productivity expressed in weight of crop produced from a unit volume of water used or diverted (kg/m^3) and combines physical and economic productivity of water expressed as net or gross current value of crop produce per unit volume of water (Rs/m^3).

Perry *et al*. (2009) reported that, water productivity can be described as output of crop per unit of water consumed while Molden *et al*. (2010a) termed it the net return for a unit of water used.

Molden *et al*. (2010a) reported the research findings of crop water productivity of onion among others as 3-10 kg/m^3 or Rs.22-74/m^3.

Perry *et al*. (2009) observed that raising water productivity typically involves adopting measures that improve water productivity and raise crop yields on irrigated land.

Molden *et al*. (2007) compiled a list of crops from various researchers in India indicating increased water productivity and crop yield resulting from shifting from conventional surface irrigation to drip irrigation.

Oweis *et al*. (2009) reported that where water is more limiting than land, it is better to maximize yield per unit of water and not yield per unit of land. Limited or deficit irrigation is increasingly becoming an accepted strategy among others for addressing this need particularly in West Asia and North Africa.

Maina *et al*. (2017) evaluated physical water productivity for different crops grown in Uttar Pradesh and observed that among the *kharif* cereal crops grown in the state, the highest water productivity was found to be for bajra crops with 1.749, 1.248 and 0.796 kg/m^3 in Eastern, Central and Bundelkhand region, respectively while in Western region it was found highest for maize crop (1.67 kg/m^3) followed by the bajra crop. However, minimum water productivity was established for rice crops with 0.709, 0.708, and 0.313 kg/m^3 in the Eastern, Central, and Bundelkhand regions, respectively.As for *kharif* pulses the maximum water productivity was witnessed in arhar crop and minimum in moong crop throughout the regions of the state. Conversely, water productivity of all *kharif*pulses was minimum ranging from 0.099 to 0.404 kg/m^3 in Western region compared to other regions. *Apparently no evaluation was conducted for onion crop in the research.*

Messay *et al*., (2020) carried out an experiment during the 2017/2018 irrigation season at the Sekota woreda irrigation scheme to assess the water productivity of onion by using three different types of furrow irrigation methods; Alternating furrow irrigation (AFI), Conventional furrow irrigation (CFI), and Fixed furrow irrigation, set up in RCBD with four replications. Each irrigation method was provided with 75% irrigation water requirement. The results showed that the total irrigation water applied to the AFI and FFI treatments was half (3,038 m^3) as much as was applied to the CFI treatment (6,078 m^3) respectively without causing significant reduction in onion yield production whereas the AFI water productivity was statistically significantly different from FFI and CFI, being 4.05 kg m^{-3} for AFI, 3.16 kg m^{-3} for FFI and 2.15 kgm^{-3} for CFI. AFI method saved water sufficient to double irrigated area, while minimizing loss in crop production.

2. Deficit Irrigation and Water Productivity of Onion

Enchalew *et al*. (2016) carried out a field study on clay loam soil to estimate water productivity of onion and evaluate the effect of water deficit on onion yield under drip irrigation with five DI treatment levels of 90%, 80%, 70%, 60%, and 50% crop water use (ETc) and100% ETc as control, laid out in RCBD design with three replications. Results indicated that deficit irrigation (DI) improves water productivity by up to 20% without significantly affecting yield, leading to water saving of up to 45 to 108 mm depth of water from the gross onion irrigation water requirement. Similarly, results showed that marketable bulb yield was influenced by DI with the control treatment giving the highest bulb yield, which was not significantly different from treatment receiving 90% ETc. On the other hand, the yield response factor was found to range from0.8 to1.7.The highest total bulb yields of 15,690 kg/ha was observed from a control treatment. The treatment receiving 70% ETc gave the highest water productivity of onion bulb yield. However, the effect of mulches was not tested.

Teferi (2015) conducted a two year field experiment from 2013 to2014 to evaluate the effect of deficit irrigation technology on yield and water productivity of onion. Three irrigation treatments of 100, 80 and 60% ETc were applied through drip irrigation. Results indicated that the application of 100% ETc gave considerably higher onion yield compared to 80 and 60% ETc. Similarly, irrigation water productivity was found highest with 7.60 kg m^{-3} at 60% ETc. The amount of water saved at 100, 80 and 60% ETc was found to increase progressively to the highest at 57.6% and this would be used to irrigate more area of onion crop in which the earnings would lead to improved economic returns.

Zheng *et al*. (2013) carried out a two year experiment in the arid region of Northwest China under drip irrigation and plastic mulch to investigate an appropriate irrigation management strategy which could simultaneously increase onion yields and water productivity by considering eight treatments, four of which involved different levels of water stress throughout the crop season, and the other four included water stress applied at the establishment, development, bulbification and ripening stages. The findings revealed that water deficit application could be avoided during the critical stages of development and bulbification, but only small deficits could be applied during the entire crop season.

Patel *et al.*, (2013) stated that India has the largest area under onion (*Allium cape*) crop but has a considerably lower average productivity (14.21 t/ha) compared to the world's average (19.4 t/ha). In addition to low productivity, irrigation efficiencies are similarly very low (30-35%) in India. Results of a field study conducted for three years from 2007 to 2010 to evaluate the effect of DI on onion yield and its quality led them to propose DI of 20% or 40% (less water application) among other methods as an option for managing onion crop with inadequate irrigation water availability to maximize water productivity through subsurface drip irrigation. Saving of water through DI may be used to irrigate additional cropped area for the production of onion crop in a large scale to offset the high cost of onion.

Bekele *et al*. (2007) conducted an experiment to assess the effect of regulated deficit irrigation on the yield and water productivity of drip-irrigated onion. The water deficit irrigation treatment levels applied comprised 25%ETc, 50%ETc, and 75%ETc and the findings indicated that water deficit at first and fourth growth stages, gave non-significantly different yields from the optimum application (no stress treatment). Maximum yields were obtained in the full irrigation treatment whereas the minimum yield occurred in the fully stressed treatment. Similarly, all the deficit irrigations increased the water productivity of onion by stressing the crop during the first growth stage to a maximum by partially stressing the crop at 75%ETc of the optimum application level during the growing season.

Abdul *et al*. (2019) carried out a study to evaluate the influence of sowing methods and mulch on water productivity of wheat under deficit irrigation and they found that application of maize stover as surface mulch improved wheat yield. Similarly, irrigation under both full irrigation and 20% deficit irrigation resulted in increased wheat yield, yield components, and water productivity with non-significant differences.

Walle *et al.*, (2014), investigated the influence of deficit irrigation through drip irrigation and mulching material on the yield and water productivity of onion in low land region of north-central Ethiopia. The study involved three irrigation levels as main blocks and three mulching rates as sub-blocks. The drip irrigation levels comprised full irrigation, mid irrigation and half irrigation levels. A control plot and mulching material of dry straw with two different application rates were applied to reduce soil moisture evaporation loss. The results showed that marketable yield was considerably influenced by both irrigation level and mulching rate.

Adem *et al*.(2006) carried out a four-year field study (1998/1999 to 2001/2002) at Ankara Research Institute of Rural Services to assess the impact of two deficit irrigation levels of 1/3 and 2/3 of the full irrigation treatments on wheat yield and water use efficiency. The results showed that grain yields (5120, 5170 and 5350 kg/ha) obtained by applying 1/3, 2/3 and full Supplemental Irrigation, respectively were non-significantly different. The mean productivity of irrigation water ranged from 3.70 kg/m3 to 4.5 kg/m3. The water productivity of 1/3, 2/3 DI were 2.39 and 1.46, respectively, compared to rainwater productivity of 0.96 kg/m3.

Sander *et al*. (2004) reported that the agricultural sector has the challenge of producing more food from less water and that this can be alleviated by increasing Crop Water Productivity (CWP). A review of more than 84 literature sources with experiment results less than 25 years old, found that the ranges of CWP of wheat, rice, cotton and maize is very large and therefore offers remarkable prospects for maintaining or improving agricultural production with 20–40% less water resources. They further stated that the variability of CWP can be attributed to climate, irrigation water management and soil nutrient management, among others. They concluded that crop water productivity can be increased considerably by reducing irrigation through crop water deficit application.

Geerts *et al*.(2008) proposed that the agriculture sector ought to increase its production with a diminishing amount of available freshwater through deficit irrigation (DI) which has widely been investigated as one of the possible solutions for alleviating the developing water scarcity. From the results of a controlled experiment a DI strategy was obtained which aimed at mitigating droughts during plant establishment and during the reproductive stage. The DI strategy was tested in the field for two cropping seasons (2005–2006, and 2006–2007) by applying on local agricultural practices and comparing with full irrigation and rain-fed treatments. From the field results obtained, it was evident that quinoa yields could be improved from 1.2 to 2

Mg/ha with the use of DI by applying only 50% ETc, for full irrigation.

Abdelsattar *et al.*, (2019) conducted a research to evaluate the response of onion bulb yield and irrigation water use efficiency using two levels of deficit irrigation treatments and a control by applying 50, 75, and 100% of the irrigation water requirements during three different seasons. It was observed that DI application of 75% of the irrigation water requirement occasioned low yields and profit decline for the farmers (10.3% and 10.9%, respectively) compared to full irrigation application. Similarly, it led to valuable water savings of 26.6%, hence, enhancing water productivity whereas onion exposed to DI of 50% of the irrigation water requirements significantly reduced bulb yield and farmers' profits.it was concluded that DI at 75% of the irrigation water requirements could be practiced for onion production in water-limited conditions.

3. Effect of Mulching on Yield Components and Water Productivity of onion

Mulches can consist of plant or synthetic materials comprising plastic sheets (Allen *et al*., 1998). The sheets may generally be transparent, black or white in colour. As observed by Allen *et al*., (1998), mulches tend to influence albedo mostly during the initial stage of crops. Plastic mulches greatly reduce water evaporation from the soil surface, particularly under drip irrigation. Among the advantages attributed to the use of mulches is increased soil temperature, reduced evaporation, and reduced leaching of fertilizer, reduced weed problems and cleaner product. Some of its disadvantages are higher initial cost and management.
Allen *et al.* (1998) reported that the approximate average reductions in surface evaporation for some horticultural crops, including, watermelon cucumber, tomato, and cantaloupe squash under complete plastic mulch compared with using drip irrigation system with no mulch ranged from10-30% and 50-80% respectively.

Douglas (2020) reported an increase in yields of up to four times for squash, watermelon, and pepper and three times for tomato when plastic mulching material and drip irrigation were combined.

Gregory (2004) reported that agronomic practices such as the application of mulches can reduce moisture evaporation from the soil surface, soil moisture evaporation can also be reduced by a crop canopy that shades the soil surface (Siddique *et al*. 1990b)

Mulching is among different cultural practices existing. It has some positive effects on the onion production. Mulching materials with different spectral properties have been observed to increase soil temperature and moisture retention thereby enhancing bulb development (Suh et al., Barkley et al., 1965).

Prihar (1986) found that mulch reduces the water loss by evaporation resulting in more conservation of moisture in soil.

Greisenheim (1952) reported that artificial mulching increased the growth and yield of onion.

According to Rhu*et al*. (1990) and Kashi *et al*. (2004), mulch not only conserve soil moisture, but also increases soil temperature, reduces weed problems and simulates higher crop yields by more efficient utilization of soil moisture.

Mubarak *et al*., (2018) carried out a study aimed at raising water productivity for sustainable crop production and water savings by setting up experiments under open field conditions running for two years, 2016 and 2017 to assess the effects of deficit irrigation under mulch on onion crop yield. They evaluated two soil cover systems comprising wheat straw and no-mulch and three irrigation levels of 100%, 80%, and 60% of crop evapotranspiration, with six replications. The results showed that onion plants were responsive to straw mulching whereas total yield, bulb diameter, water productivity, and dry matter were considerably enhanced under mulch irrespective of the irrigation water level applied. Similarly the results indicated the sensitivity of onion to water stress. Yield, water productivity, and dry matter were higher under full irrigation compared to the deficit irrigation. Conversely, wherever mulch was applied, deficit irrigation considerably improved water productivity.

Biswas *et al*. (2017) studied the effects of deficit irrigation and mulch on seed yield and water productivity of onion through a field experiment during 2012/2013 and 2013/2014 winter seasons. Eight treatments composed of four irrigation levels (100, 80, 60, and 40% soil moisture deficit) and two of mulching levels (rice straw and no-mulch) in a RCBD with three replications. The results indicated that both irrigation and mulch influenced the yield and yield contributing parameters of onion. Typically, the seed yield was minimum in treatment of 40% ETc without mulch and maximum in full irrigated (100% ETc) mulch treatment, respectively. The seed yields of the treatments irrigated up to 80% ETc were not statistically different from those that were fully irrigated (100% ETc). Results showed that irrigating onion up to 40% ETc reduced seed yield by about 30%. Applying water up to 60% of ETc caused a yield reduction of about 19%. However, irrigating onion up to 80% of ETc reduced seed yield by less than 4%. Results also indicated that onion crop water use was mostly influenced by the depths of applied water rather than mulching. On average, total water use ranged from 177 to 262 mm with minimum in mulch treatment of 40% ETc and maximum in full irrigated treatment. The total amount of water used by the mulched treatments was 5.08% lower than the non-mulched treatments. The mulched treatment (80% ETc) consumed 220 mm of water and was found to have the highest Water productivity of 0.71 kg m^{-3}. This treatment also produced almost as much as the highest yield with 22% saving of irrigation. It was concluded that irrigating up to 80% ETc with mulch may be the best practice for seed production of onion.

Henry *et al*. (2012) presented the findings of the effects of regulated deficit irrigation and mulch materials on yield, water use and water productivity of onion crop after conducting field experiments in 2008/09 and 2009/10 irrigation seasons by setting up sixteen treatments comprising four levels of water application depths of irrigation at 25, 50, 75, and 100% ET and four mulching levels (no-mulch, rice straws, black and white transparent polyethylene materials). The results showed that bulb yields in both seasons ranged from 6.3 to 20.6 t/ha while seasonal water applied ranged from 225 to 480 mm and the seasonal ET obtained from the soil moisture contents ranged from 201 to 376.3 mm. Further analyses of results showed that irrigating onion at 25% of reference evapotranspiration (ET) reduced bulb yield by about 50% whereas applying water at 50% of ET caused a yield reduction. Conversely watering onion at 75% of ET, reduced bulb yield by up to 10%. Results further indicated that irrigating the crop at 50% and 75% of ET gave higher crop water productivity. Mulching with black polyethylene or rice straw considerably improved the crop water productivity of the onion crop. The researcher recommended mulching with rice or black polyethylene and water application depth per irrigation to be maintained at 50–75% weekly reference evapotranspiration to maximize irrigation water utilization under limited water supply and improve crop water productivity in the study area

Ramalan *et al*. (2010) conducted a study during the 2008/2009 dry season to evaluate the effect of deficit irrigation and different mulch covers on water use and yield of drip irrigated onion (Bombay Red cultivar). The set up comprised deficit irrigation at four levels (0, 25, 50 and 75% of Total Available Water) and four different types of mulch covers (bare soil or no mulch, clear plastic, black plastic and straw mulch) combined in a randomized complete block in three replications. The results indicated that onion bulb yield reduced with rise in levels of water stress. In contrast, both irrigation water use efficiencies and crop water use increased as water deficit level increased. It was concluded that mulching significantly increased bulb yield while reducing water use thereby increasing water productivity.

Suh *et al*., (1991) performed a study on the improvement of the mulching cultivation technique for onions and ascertained that mulching caused considerable variation in Onion plant height, recording a maximum height of 45.38 cm from sawdust mulching whereas the control had the minimum of 39.02 cm. The plant heights observed three months later after transplanting under burnt soils, ash and rice husk were 39.74, 42.56 and 42.98 cm respectively. It was established that mulching effects caused an increase plant heights possibly due to retention of more soil moisture as well as lower soil temperature throughout the growing season while the control plants lacked the said benefits.

4. Economics of Deficit Irrigation

To appreciate the potential benefits of DI, it is extremely important to understand that the application of irrigation water is expensive, the efficiency of irrigation water diminishes with increase in application depth, the water saved by reducing irrigation depth can be used to extend the amount of land irrigated and that the determination of an optimal irrigation strategy depends on whether a shortage of land or of water is the limiting production factor (English, 1990; English and Raja, 1996; Lecler, 1998).

An experimental trial was carried out by Capra *et al*. (2008) during 2005 and 2006 to evaluate the effect of four different irrigation levels comprising 50, 75, 100 and 125% of the evapotranspiration rate on the yield components, marketable yield and economic return of the crop using drip irrigation on a lettuce crop. The results revealed that highest mean marketable yield (t/ha) was noted in plots which received 100% of ETo (reference evapotranspiration by Penman-Montheith method) applied water. Where the land was limiting, the estimated optimal economic levels were relatively comparable to the optimal agronomic levels (100-130% ETo) whereas for the water-limiting case, the produce that were as profitable as that from full irrigation were those from DI ranges 15-44% ETo and 74-94% ETo in 2005 and 2006, respectively.

Dale *et al*. (2018) developed an agro-economic model which relates plant growth stage specific evapotranspiration (ET) targets with farm profitability and used it to establish the economic conditions at which targets of less than 100% ET are optimal for maximizing profit of crops for farmers. The results of the study proposed that farmers could counter the rising water scarcity using deficit irrigation, but only within a range of water costs that depends on production costs and output price.

Rao *et al*. (2019) carried out a study in PFDC field, ICAR-CIAE Bhopal to evaluate the growth, water use efficiency and field economics of onion under different micro irrigation systems. The study comprised four irrigation methods (Drip, Perforated pipe, Flood irrigation and Sprinkler methods) combined with deficit irrigation. The results showed that higher onion yield and large sized onion were obtained with the drip irrigation method at almost half the quantity of water requirement. The conclusion drawn from the results was that this was due to the reason that drip irrigation system allows for more frequent and shallow irrigation depths with higher irrigation efficiency.

Rodrigues GC *et al*., (2009) in an experiment aimed at evaluating the viability of deficit irrigation of some crops comprising maize, wheat and sunflower through an analysis of the economic water productivity (EWP) in Vigia Irrigation District, Southern considered various scenarios of water deficits and water availability and calculated from data collected from the field on yield values, water costs, production costs, irrigation and commodity prices performance, indicators on EWP. The results showed that adopting deficit irrigation requires not only an appropriate irrigation scheduling, but higher irrigation performance and the application of a flexible water prices policy, thereby supporting the enhancement of the irrigation systems.

Thisstudy will be useful for deciding the optimum level of onion production and water productivity relative to water application levels and type of mulching with respect to saving water in the event of scarcity where water resources are limited, whereas land is unlimited.

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References

[1] Abdelsattar A, Nuria PS, Inmaculada N, Miguel ÁD, Carlos B and Bernardo P. 2019.Effect of Deficit Irrigation on the Productive Response of Drip-irrigated Onion (*Allium cepa L.*) in Mediterranean Conditions.The Horticulture Journal 88(4).

[2] Abdul R, Muhammad JK, Tahir S and Mohammad JK. 2019. Influence of Deficit irrigation, sowing methods and Mulching on yield components and yield of wheat in semiarid environment. Journal of Botany 51(2):553-560.

[3] Adem I,Haluk U, Theib O, Mustafa P,Bogachan B. 2006. Wheat water productivity and yield in a cool highland environment. Journal of Agricultural Water Management 82(3):399-410.

[4] Allen RG, Pereira LS, Raes D and Smith M. 1998. Guidelines for computing crop water requirements. FAO, Rome Italy. 326p.

[5] Bhagyawant RG, Gorantiwar SD and Dahiwalkar SD. 2015. Yield Response Factor for Onion (*Allium Cepa L*) Crop Under Deficit Irrigation in Semiarid Tropics of Maharashtra. Current Agriculture Research Journal 3(2):128-136.

[6] Bekele S, Zeleke K. 2007. Regulated deficit irrigation scheduling of Onion in a semiarid region of Ethiopia. Journal of Agricultural Water Management 89(1):148-152.

[7] Biswas SK, Roy DK, Sarkar KK, Milla AJ, Murad KFI and Anower MA. 2017. Effects of Deficit Irrigation and Mulching on Seed Yield and Water Use of Onion (*Allium cepa L.*). International Journal of Plant and Soil Science 20(3): 1-10.

[8] Capra A, Consoli S and Scicolone B. 2008. Agricultural Irrigation Research Progress. Publ. Nova Science. Inc. Italy. P54.

[9] Dale TM, Salvador L, Louise HC, Thomas T, Steven JF, Nora F. 2018.Economic viability of deficit irrigation in the Western US.Agricultural Water Management 196:114-123.

[10] Douglas CS. 2020. Using plastic mulches and drip irrigation for vegetable production. http://www.ces.ncsu.edu/depts/hort. Accessed 06/12/2020.

[11] Enchalew B, Gebre Sl, Rabo M, Hindaye B, Kedir M, Musa Y, Shafi A. 2016. Effect of Deficit Irrigation on Water Productivity of Onion (*Allium cepa L.*) under Drip Irrigation. Irrigation and Drainage Systems Engineering 5(3):172.

[12] English M. 1990. Deficit Irrigation. Analytical Framework. Journal of Irrigation and Drainage 116:399-412.

[13] English MJ and Raja SN. 1996. Perspective on deficit irrigation. Agricultural Water Management Journal 32:1-14.

[14] Geerts S, and Dirk R. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Journal of Agricultural Water Management 96(9):1275-1284.

[15] Geerts S, Dirk R, Magali G, Jean V, Richard M, Jorge M, Ruben H, Bernardo M, Roberto M, Jorge C andCristal T. 2008. Introducing deficit irrigation to stabilize yields of quinoa (*Chenopodium quinoa Wild*). European Journal of Agronomy 28(3):427-436.

[16] Gregory P. 2004. Agronomic approaches to increasing water use efficiency. *In:* Water use efficiency in plant biology (Eds Bacon M). Blackwell, Oxford. 142-170.

[17] Greisenheim AM. 1952. Mulching trials with tomatoes, cucumbers, onion, carrots and dwarf beans. Beg. Lehr. U. Forsch. Anst. Geisenhaim Rhim, p37.

[18] Henry EI, Ramalan AA and Oiganji E. 2012. Effects of Regulated Deficit Irrigation and Mulch on Yield, Water Use and Crop Water Productivity of Onion in Samaru, Nigeria. Journal of Agricultural Water Management. 109:162-109.

[19] Kashi A, Hosseinzadeh S, Babalar M, Lessani H. 2004. Effect of black polyethylene mulch and calcium nitrate application on growth and yield of watermelon (*Citrulluslanatus L*). Journal of Science and Technology of Agriculture and Natural Resources 7:1–10.

[20] Kipkorir EC, Raes D and Labadie J. 2001. Optimal allocation of short-term irrigation supply. Journal of Irrigation and Drainage Systems 15: 247-267.

[21] Kirda C, Moutonnet P, Hera C, and Nielsen DR. 1999.Crop yield response to deficit irrigation.Replika Press Pvt. Ltd. India. 258p.

[22] Kumar DM, Singh OP, Samad M, Turral H and Purohit C. 2008. Water Productivity of Irrigated Agriculture in India: Potential Areas for Improvement, published in proceedings of the 7th Annual Partners" Meet on "Managing Water in the Face of Growing Scarcity, Inequity and Declining Returns: Exploring Fresh Approach I: 121-140.

[23] Lecler NL .1998. Integrated methods and models for deficit irrigation planning. *In:* (Eds Pert RM, Curry RB) Agricultural systems modelling and simulation, Marcel Dekker, Inc. NY. p283-29

[24] Maina K, Singh OP and Dinesh CM .2017. Crop Water Requirement, Water Productivity and Comparative Advantage of Crop Production in Different Regions of Uttar Pradesh, India. International Journal of Current Microbiology and Applied Sciences 6(7): 2043-2052.

[25] Temesgen T, Ayana M and Bedadi B. 2018. Evaluating the Effects of Deficit Irrigation on Yield and Water Productivity of Furrow Irrigated Onion (*Allium cepa L.*) in Ambo, Western Ethiopia. Irrigation and Drainage Systems Engineering 7(1):203.

[26] Molden D, Oweis T, Steduto P , Bindraban P, Hanjra MA , Kijne J. 2010a. Improving agricultural water productivity: Between optimism and caution. Journal of Agricultural Water Management97: 528–535.

[27] Molden D, Oweis TY, Pasquale S, Kijne JW, Hanjra MA, Bindraban PS, Bouman BAM, Cook S, Erenstein O, Farahani H, Hachum A, Hoogeveen J, Mahoo H, Nangia V, Peden D, Sikka A, Silva P, Turral Hugh, Upadhyaya A, Zwart S. 2007. Pathways for increasing agricultural water productivity. *In:* Water for food, water for life (Ed Molden D). A Comprehensive Assessment of Water Management in Agriculture. London, UK: Earthscan; Colombo, Sri Lanka.279-310.

[28] Mubarak I and Hamdan A. 2018. Onion Crop Response to Regulated Deficit Irrigation under *Mulching* in Dry Mediterranean Region. Journal of Horticultural Research 26(1): 87-94.
[29] Oweis T, Hachum A. 2009. Supplemental irrigation for improved rainfed agriculture in WANA region. *In:* (Eds Wani SP, Rockstrom J, Oweis T). Rainfed agriculture: Unlocking the potential. Comprehensive Assessment of Water Management in Agriculture. CABI, London, UK 182-196.
[30] Pandey RK, Maranville, JW, Chetima MM. 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment. Journal of Agricultural Water Management 46:15-27.
[31] Patel N and Rajput TBS. 2013. Effect of deficit irrigation on crop growth, yield and quality of onion in subsurface drip irrigation. International Journal of Plant Production 7(3)1735-8043.
[32] Perry C, Pasquale S, Allen RG, Burt CM. 2009. Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities.Agricultural Water Management 96:1517-1524.
[33] Prihar SS. 1986. Fertilizer and water use efficiency in relation to mulching. Indian Journal of Agronomy 32: 452-454.
[34] Ramalan AA, Nega H and Oyebode MA. 2010. Effect of deficit irrigation and mulch on water use and yield of drip irrigated onions. Journal of Sustainable Irrigation Management, Technologies and Policies 134:40-50.
[35] Rao KVR, Suchi G, Pushplata A and Deepika Y. 2019. Growth, yield, economics and water use efficiency of onion (*Allium cepa L.*) under different micro irrigation systems. Journal of Pharmacognosy and Phytochemistry 8(3):3866-3869.
[36] Rhu AK, Mushi AAA, Khan MAH. 1990. Effect of different mulches on the growth of potato (*Solanum tuberosum L.*). Bangladesh Journal of Botany 19:41-46.
[37] Rodrigues GC and Luis SP. 2009. Assessing economic impacts of deficit irrigation as related to water productivity and water costs. Journal of Biosystems Engineering 103:536-551.
[38] Sander JZW, Bastiaanssen GM. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Journal of Agricultural Water Management 69(2):115-133.
[39] Siddique KHM, Tennant D, Perry MW, Belford RK. 1990b. Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. Australian Journal of Agricultural Research 41(3):431-447
[40] Stegman EC, Musick JT and Stewart JI. 1980. Irrigation water management. In: Jensen ME (Ed) Design and Operation of Farm Irrigation Systems (pp. 763-816). ASAE Monograph 3, St. Joseph, Michigan.
[41] Stewart JI, Cuenca RH, Pruitt WO, Hagan, RM and Tosso J. 1977. Determination and utilization of water production functions for principal California crops. Davis, United States of America, University of California.
[42] Suh JK, Kim YB, Lee YS, Lee KS and Ham KY. 1991. A study on the improvement of the mulching cultivation method for onions (*Allium repa* L.). Res. Rep. Rural Dev. Admin. Hortic.33:21-28.
[43] Teferi G. 2015. Effect of Drip and Surface Irrigation Methods on Yield and Water Use Efficiency of Onion (*Allium Cepa L.*) under Semi-Arid Condition of Northern Ethiopia. Journal of Biology, Agriculture and Healthcare 5(14):88.
[44] Temesgen T, Ayana M and Bedadi B. 2018. Evaluating the Effects of Deficit Irrigation on Yield and Water Productivity of Furrow Irrigated Onion (*Allium cepa L.*) in Ambo, Western Ethiopia. Irrigation and Drainage Systems Engineering 7(1):203.
[45] Ünlü M, Kanber R, Senyigit U, Onaran H, Diker K. 2006. Trickle and sprinkler irrigation of potato (*Solanum tuberosum L.*) in the middle Anatolian region in Turkey. Journal of Agricultural Water Management 79:43-71.
[46] Walle JL, Belayneh AA, Lewoye TA. 2014. Yield and Water Use Efficiency of Mulched Drip-Irrigated Onion in Low Land Region of Amhara, North Central Ethiopia. Universal Journal of Agricultural Research 2(6):203-210.
[47] Zheng J, Huang G, Wang J. 2013. Effects of water deficits on growth, yield and water productivity of drip-irrigated onion (*Allium cepa L.*) in an arid region of Northwest China. Journal of Irrigation Science 31:995-1008.