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Review Article

Research Achievements, Challenges and Future Perspectives of Irrigation and Water Harvesting Research Program of Jimma Agricultural Research Center: A Review

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ABSTRACT

Rainfall rarely meets the time with the required amount of water application for plant growth because of spatial and temporal variability and due to this there was a low production. Thus, for a sustainable increase in agricultural production and productivity, the intervention of irrigation is essential. Jimma Agricultural Research Center has been conducting a lot of irrigation and water harvesting research and also generated essential research findings for its mandate area from its establishment for the last one and half a decade. The objective of this review is to document the major achievement of Irrigation and water harvesting, challenges and future prospects. The study was conducted by reviewing the secondary data documents available on the web and through interviewing the previous researchers who conducted research and also research documents that are available in the library of the Jimma Agricultural Research center. Accordingly, the major research activities conducted in Jimma Agricultural Research Center under the irrigation and water harvesting program on coffee crops were, Dry matter partitioning and physiological responses of *Coffea arabica* varieties to soil moisture deficit stress at the seedling stage in Southwest Ethiopia, Growth Response of Hararghie Coffee Accessions to Soil Moisture Stress at Seedling, Sensitivity of coffee Genotypes to Drought Induced by Soil Drying at Early Growth stages, Growth and plant water relations of *Arabica coffee* in response to deficit irrigation, Determination of Optimal irrigation scheduling for coffee and Estimation and mapping of coffee water requirement using models. The major challenges were lack of irrigation infrastructure, lack of green house and shelter, and lack of laboratory equipment. The future irrigation research will focus on climate change, salinity, ground water monitoring, watershed-based irrigation, modelling, more advanced technology such as GIS and remote sensing.

Keywords: Achievements; Challenges; Coffee; Irrigation; Water harvesting

INTRODUCTION

Agriculture is the primary source of income in Ethiopia, accounting for 34.8% of the country's GDP, more than 80% of total exports, and 72.7% of total employment [1]. Though it is the primary source of income and contributes significantly to the country's GDP, the agricultural system is primarily based on rain-fed farming, which is dependent on unreliable rainfall and thus puts the sector at risk of low production and productivity. Unfortunately, the country's population is on an increasing trend and is projected to reach 120 million people in 2022 [2]. This demands an additional increase in agricultural production to meet the food supply of the country. Since the country is lucky to have ample surface and ground water resources and has been given the prestige of being called the "water tower of East Africa," there was an option to use the resource sustainably.

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Many perennial and annual rivers exist in the country. Quite a significant number of lakes, dams, and reservoirs are also found in various parts of Ethiopia.

Commonly, the production of a crop is a function of water, nutrient, climate, and soil environment provided that all other requirements are adequate for proper growth and production. Rainfall rarely meets the time with the required amount of water application for plant growth because of spatial and temporal variability and there was a low production. Thus, for a sustainable increase in agricultural production and productivity, the intervention of irrigation is essential. The basic purpose of irrigation is to provide plants with water to meet full crop evapotranspiration thereby obtaining optimum crop yield and maximum water use efficiency. It implies the application of suitable water to crops the right quantity of water at the right time. Salient features of any improved method of irrigation are the controlled application of the required amount of water at desired time, which leads to minimization of range of variation of the moisture content in the root zone, thus reducing stress on the plants.

Because the agricultural production system in Ethiopia is dependent on rainfall, the production and productivity of the crop are low and the agricultural system is unreliable as a result of the erratic nature of rainfall [3]. The sector has to adopt irrigated agriculture for production improvement and reliability of agricultural production, in addition to transforming the rainfed agricultural system into a combined rain fed and irrigation agriculture system. Even though there is an ample amount of rainfall in the south-western part of the country, the spatial and temporal variability of the rainfall necessitates irrigation. According to the study conducted by Tadesse (2019) [4], more than 70% of the rainfall occurs during the summer season, mainly from June to September. The typical example that indicates the necessity of irrigation is the shifting of cropping time (planting date) of the crop as compared to the previous.

Irrigation is basically essential for enhancing food production, promoting economic growth and sustainable development, creating job opportunities, and improving the living conditions of individual farmers or farmers organized in a cluster form. Its purpose is mainly to enable effective management of irrigation to apply the right amount of water at the right time. Accurately estimating the volume of water required at different growth stages for cultivated crops is essential for the efficient use of available finite water resources. Furthermore, understanding crop water requirements allows for maximum yields by controlling over or under irrigation issues such as waterlogging or insufficient water at the root zone, salinization of soil, and water stress to plants, all of which can reduce crop yields. As a result, institutional and organizational arrangements for irrigation water management are required for the effective use of irrigation for crop production in various agro-ecologies.

The establishment of agricultural water management programs in research centers under the Ethiopian Institute of Agricultural Research, including Jimma Agricultural Research Center, is for the generation of technologies and information that are necessary for the optimum use of water resources sustainably. For agricultural water management (irrigation water management), determining the specific nature of the crop, evapotranspiration of the crop and irrigation water requirement of the crop is essential. Since its establishment, the Jimma Agricultural Research Center has been conducting a lot of irrigation and water harvesting research and has also generated essential research findings for its mandate area.

The objective of this review was to document the major achievements in irrigation and water harvesting research, as well as the challenges and future prospects of the irrigation and water harvesting research program in Jimma Agricultural Research Center.

ABOUT THE STUDY

The study was conducted by reviewing the secondary data documents which were conducted in the Jimma Agricultural Research Center and are available on the web and by interviewing the previous researchers who conducted research and also reviewing research documents that are available in the library of the Jimma Agricultural Research Center.

MAJOR ACHIEVEMENTS

Dry matter partitioning and physiological responses of *Coffea arabica* varieties to soil moisture deficit stress at the seedling stage in Southwest Ethiopia

Drought, which was induced due to climate variability, will cause water stress and a deficit for crop production. It affects the growth, yield, and quality of crops. According to Yackob *et al.* [5], as cited by Worku and Astatike [6], some crops use defensive mechanisms such as maximizing water uptake or osmotic adjustment for tolerating water-related problems, and coffee also has some physiological defensive mechanisms. Hence, considering the problem of water scarcity and stress, a study was conducted at the Jimma Agricultural Research Center [6].

The objective of the study was to select coffee varieties that resist soil moisture deficit stress at the seedling stage. They mainly focus on testing the morphological and physiological traits that contribute to varietal differences in water stress responses, the impact of water stress on dry matter partitioning, leaf chemical concentration, and relative water content, and differences among genotypes differing in their canopy architecture in the extent of their responses to water stress and recovery periods. To achieve this, they have selected six varieties with three canopy natures, namely, 741 and 744 open coffee canopy, 7440 and 7487 medium open coffee canopy, and 74140 and 74148 compact coffee canopies. All the necessary nursery management mechanisms recommended were also implemented.

For conducting the study growth parameter of the coffee seedling such as fresh and oven dry weight of leaves, shoots, roots and total dry matter were measured. Leaf mass ratio (LMR=leaf dry weight/total dry matter), shoot mass ratio (SMR=shoot dry weight/total dry matter), root mass ratio (RMR=root dry weight/total dry matter) and root to shoot ratio (RSR=root dry weight/shoot dry weight) were calculated to assess the effect of drought on dry matter partitioning and also physiological responses, namely number of Wilted Seedlings (WS), Percentage of Rolled Leaves (LF), Stomatal Resistance (SR), Relative Water Content (RWC) and Leaf Temperature (LT) were measured before inducing drought stress, after 15 and 30 days of water stress periods, and at the end of 15 days recovery period [6].

Leaf Chemical concentration were determined and the gravimetric water content was also measured procedurally [6].

Their finding reveals that the leaf P content, with the exception of varieties 74148 and 744, decreased during the stress and recovery periods with lower rates of reduction during recovery. The accumulation of nutrients in plant tissues is considered an indicator of water use efficiency and drought stress tolerance. For varieties 741 and 7440, multiple mean comparisons of SMR revealed a significant increase during the water deficit stress period. Multiple mean comparison of the six varieties indicated that varieties 7440, 7487, 74140, and 74148 had more dry matter to roots than to shoots, showing the highest root to mass ratio and root to shoot ratio.

The study also showed that a 30-day water deficit brings significant morphological and physiological changes to coffee, and that coffee plants cope with drought stress through both morphological and physiological mechanisms. This showed that the varieties reduced transpiration by leaf rolling and stomatal closure. minimizing drought effects by leaf folding and a high correlation of leaf folding with leaf area, leaf dry weight, and leaf water content) for CBD resistant varieties was also observed [5].

Screening of coffee genotypes for drought tolerance

Growth response of hararghie coffee accessions to soil moisture stress at seedling: For the management of drought [7], morphological and physiochemical/biochemical mechanisms of plants that resist water deficit have to be initiated. Coffee is a highly environmentally dependent crop, and an increase of a few degrees in average temperature and/or short periods of drought in coffee-growing regions can substantially decrease yields and quality of coffee. Different research on drought tolerance in coffee has been conducted using pot-grown seedlings under a greenhouse. Similarly, an experiment was conducted in the Jimma Agricultural Research Center to determine the growth response of Hararghie Coffee Accessions to soil moisture stress at seedling stage.

According to the study, there was a significant difference among the genotypes for sensitivity to water stress imposed under the rain shelter at Jimma Agricultural Research Center. Accession H-915/98 and H-929/98 showed significantly higher mean stress score values, whereas H-857/98 and H-981/98 showed lower values [8]. Total dry matter yield and root to shoot ratio were higher for accession H-857/98. Similarly, relative leaf water content and leaf thickness of accession H-857/98 were significantly higher, while the rate of recovery was higher for accession H-857/98 and 74110 [8]. Drought resistant coffee genotypes tend to increase root lengths in order to uptake deep soil moisture water through their deep root systems and decrease leaf area in order to improve plant water status. Deeper root systems of tolerant clones enabled them to gain greater access to water towards the bottom of the pots and, therefore, to maintain more favourable internal water status for longer than drought-sensitive clones [9]. In general, among the Harerege coffees tested in this experiment, accession H-857/98 and H-856/98 showed the least stress score, higher total dry matter yield, higher relative leaf water content, better root-to-shoot ratio, and a higher rate of recovery after re-watering [8]. For cultivated plants, tolerance to drought is generally considered as the potential for a particular species or variety to yield more in comparison to others under limited soil water conditions [10].

Sensitivity of coffee genotypes to drought induced by soil drying at early stages of growth: Responses of coffee varieties to water stress were observed by reducing the specific leaf area, leaf area ratio, and growth rate of plant height and leaf area, as well as by increments in girth, root volume, and total dry matter. On the other hand, varieties responded to stress recovery by fast growth resumption and further dry matter accumulation. Stress development like leaf folding or the degree of wilting is used as important criteria during screening of genotypes for drought tolerance [11-13].

From the experiment, it was observed that there were significant differences among the cultivars for sensitivity to water deficit stress based on mean stress score, percent of plants wilting at noon and recovering during the night, mean days to complete wilting, rate of leaf shed, and rate of survival. Cultivars F-59, 7395xF-59, J-19, 7454, 754, 75227, and Geisha were identified as more sensitive than 7487, 74110xF-59, 741, J-21, 744, 741xF-59, 74158, 77/85, 7395, F-35, 74148, and 74165, while 7440, 74140, 74110, 74112, and 8/85 were relatively tolerant to the imposed soil drying treatment (Tesfaye SG, 2018). Similar work was reported for different genotypes of both Arabica and Robusta coffees [12,13]. Coffee genotypes showed different mechanisms either to avoid stress or stress tolerance and defence mechanisms against water deficit at an early growth stage. Coffee genotype seedling survival in drought prone environments depends upon the species' ability to compensate for the negative effect of low water potential in the atmosphere by adjusting root and shoot morphological and physiological patterns.

Growth and plant water relations of *Arabica coffee* in response to deficit irrigation

Water is one of the basic natural resources for agricultural production, and its availability is limited and leads to water scarcity. Water scarcity is among the significant problems that are challenging many societies in different parts of the world. In Ethiopia, water scarcity is majorly associated with economic considerations. Hence, despite abundance in some parts, the country is highly water-scarce due to a lack of water control infrastructure [11]. Mainly, spatial and temporal variability in rainfall aggravate the water scarcity problem. In addition to this, the ever-increasing world population and the demand for additional water supply by industrial, municipal, and agricultural sectors exert a lot of pressure on renewable water resources. It is a major limiting factor in crop production around the world [12]. Therefore, irrigation only based on crop water requirements is not an option, especially in areas where water resources are limited.

According to the study conducted by Silva *et al.* [13], proper coffee plant growth and bean production require sufficient moisture to increase yield and expand plantations in areas considered unsuitable due to the occurrence of water shortages. In Ethiopia, coffee seedlings are normally raised in nurseries during the dry, hot period and transplanted to the field at the beginning of the wet season. The practice of deficit irrigation is an effective water-saving method in different crops to mitigate drastic reductions in growth and yield of crops in areas of recurrent water scarcity as well as long drought periods. In this regard, experiments conducted at Jimma agricultural research center to study the effects of Normal Deficit Irrigation (NDI), Partial Root Zone Drying (PRD), and Well Watering (WW) on growth, water relations, and Irrigation Water Use Efficiency (IWUE) of the *Arabica coffee* cultivar showed that PRD controlled shoot vegetative vigor and increased root to shoot ratio, which are important to hardening off nursery grown young plants before transplanting in the field, especially in drier areas. It also increased IWUE and saved irrigation water by 50% [14].

The use of increased root to shoot ratio as well as increased IWUE is due to water deficit stress, which reduces plants' total biomass yield and the volume of water applied to the plants, respectively. In addition to this, PRD could also be an effective irrigation management strategy in the field and is more advantageous than full irrigation or NDI, as it saves water, increases IWUE, and improves crop quality without a significant reduction in crop yield. In terms of water resource utilization and crop yield and quality, Partial Root Zone Drying (PRD) and Normal Deficit Irrigation (NDI), Supplemental Deficit Irrigation (SDI) is more effective than Supplemental Full Irrigation (SFI) and rain-fed culture in terms of water resource utilization and crop yield and quality, particularly in areas where shortage of water is a critical factor in coffee production [15]. Similar results have also been reported by different authors on different crops like tomatoes, common beans, soybeans, and maize. ICARDA has shown that a 50% reduction in irrigation water applied decreased yields from 10% to 15%, and overall farm productivity increased by 38% when the water saved was used on other land [16]. Payero *et al.* [17] reported that water deficits can affect the growth, development, and physiological processes of maize plants, which reduces biomass yield. Under deficit irrigation, crop producers allow the crop to experience some water stress, but the water saved should allow an increase in the area irrigated, or it could be used for production [18].

Determination of optimal irrigation scheduling for coffee

Effective use of available water with appropriate irrigation scheduling has a significant impact on irrigated agriculture since water scarcity is the most critical constraint for the development of agriculture. Optimization of soil moisture depletion levels is a major limiting factor in coffee production systems. The scheduling of irrigation for coffee was based on an FAO recommendation and requires adjustment to local conditions. Hence, effective use of available water with appropriate irrigation scheduling has a significant impact on irrigated agriculture.

To validate FAO depletion (p-factor), an experiment was conducted with the objective of determining the appropriate optimal soil moisture depletion level for coffee. Thus, an experiment was conducted at Gera, in the south-west of Ethiopia, to investigate the effect of optimal soil moisture depletion level on growth, yield, and water productivity of coffee. The irrigation water was applied based on allowable soil moisture depletion (p=40%) [19]. from the results obtained, there was a significant difference among treatments for coffee yield. The maximum, minimum yield, and plant height were obtained from the 120% and FAO recommended soil moisture depletion levels, respectively. A reduction of yield was observed at 60% ASMDL as compared to a 120% ASMDL treatment [20]. The reduction of coffee yield beyond 120% ASMDL treatment is due to the induction of soil moisture stress, which consequently leads to plants stressed [21]. Different authors observed that reducing and increasing the amount of water applied at different intervals significantly affected the yield of different crops [22]. Robel *et al.* [16] have also reported that the maximum or minimum soil moisture depletion level reduced maize crop yield. Over-irrigation decreased seed yield by 24.3% when irrigated at a 60% soil moisture depletion level [16]. This may be due to the frequent application of water that leaches out important plant nutrients from the roots.

Estimation and mapping of coffee water requirement using models

Crop water requirements vary in time and space due to climate, soil, and water management conditions, phonological stage of the crop, and cultivar, hence, their assessment is better locally [23]. The spatiotemporal distribution of rainfall is of great importance in the management of water resources and has a direct influence on human activities such as livestock management, agricultural water management, and economic activity. This distribution can be studied statically through the application of simulation models and spatiotemporal geostatistical analysis. The role of simulation models in understanding the processes in the soil-plant-atmosphere system has increased significantly in recent years [24]. Several alternative schedules were generated and evaluated according to impacts on yields and on percolation of excess applied water referring to each soil type and to conditions of very low, average, high, and very high demand [25].

Climate and water are the major environmental factors affecting crop water requirements, which limits plant growth [26]. Hence, irrigation plays a significant role in increasing the productivity of important crops by providing the necessary demand for water at the required time. This includes coffee. Food demand can be fulfilled through yield increment, expansion of agricultural land and increasing cropping intensity by growing two or more crops per year using irrigation [27]. But the dependence on rainfall has a negative impact on crop production due to the erratic nature of rainfall. According to the study conducted by Tadesse (2019) [4], in the Jimma zone, the temporal and spatial distribution of rainfall throughout the year is unevenly distributed. Over 71.1% of rainfall was during the rainy summer season (June to September), while the remaining 28.9% was received during the eight months (October to May). This means that atmospheric water demand is greater than falling rainfall during dry spells. To achieve effective planning on irrigation water management, accurate information is needed for crop water requirements [28-32].

The reference evapotranspiration (ETo), coffee water requirement and irrigation requirement were mapped for the Jimma zone. The results have shown that the ETo, coffee ETc, and IR have shown moderate to greater variability. The high annual and monthly coffee ETc values were observed around the extreme eastern tip, extreme southern tip, and north-western tip. In contrast, low ETc values were observed in the southern and western regions. The high annual coffee IR locations include the northern and eastern parts, whereas the low locations are in the western and southern parts (Figure 1). Tadesse (2019) [4] reports that the highest ETo value was recorded in March (4.61 mm day-1) and the lowest in July (2.91 mm day-1) while the monthly mean coffee ETc ranged from 80.9 mm (November) to 131.11 mm (April). The coffee ETc for the Jimma zone is a good indicator and benefits the coffee farmers in planning the water resources of the area for best agricultural water management practices [4,33-35].

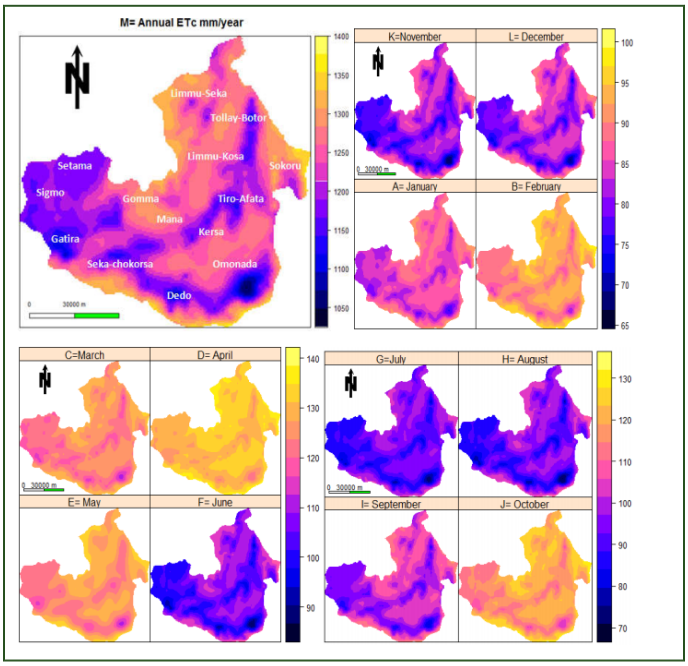

Figure 1: Crop water requirement of coffee in Jimma zone [4].

CHALLENGES

Commonly the globe is full of challenge that is the reason why human beings are struggling for survival, to study the nature or to modify the nature they existed on it. In this regard, the major challenges were the lack of irrigation infrastructure and the lack of laboratory equipment. The other minor challenge, which was not proven scientifically, is the perception of some literates and farmers saying that irrigation is not necessary for the Jimma zone. It has been proven that irrigation is essential for the Jimma zone.

FUTURE PERSPECTIVES

Future irrigation research will focus on climate change, salinity, ground water monitoring, watershed-based irrigation, modeling, more advanced technology such as GIS and remote sensing.

It continues determining the coffee crop's water requirements.

The determination of the crop coefficient (KC) of coffee through the application of lysimeter

Adoption of a more efficient irrigation method such as drip irrigation for the production and productivity improvement of coffee

It needs to determine the crop water requirement and crop coefficient for hybrid coffee.

There needs to work more investigation on water savings through integrated use of fertilizer (fertigation), mulch, and by increasing the population density of the crop per hectar and cova planting.

Verification, demonstration, and popularization of the research achievements to the farmers.

SUMMARY AND CONCLUSION

In summary, several researchers investigated a lot of irrigation information as well as technologies. Through the application of different irrigation research, it is possible to recognize that farmers benefit from applying water-saving technology and academicians also benefit from using it as a reference and as a bench mark for conducting further research activities. From the different research achievements, it is essential to avoid repetition of the activities and possible for other research activities.

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