# PHENOTYPIC PLASTICITY AND YIELD RESPONSE OF COMMON BEAN (*Phaseolus vulgaris* L.)VARIETIES UNDER DIFFERENT SOIL MOISTURE LEVELS AT HAWASSA, SOUTHERN ETHIOPIA

**M.Sc. THESIS**

**REFISA JEBESSA GELETA**

**HAWASSA UNIVERSITY**

**COLLEGE OF AGRICULTURE**

**HAWASSA, ETHIOPIA**
**AUGUST, 2020**

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**REFISA JEBESSA GELETA**

**MAJOR-ADVISOR: AMSALU GOBENA (PhD)**

**CO-ADVISOR: MESERET TESEMA (PhD)**

**THESIS SUBMITTED TO HAWASSA UNIVERSITY DEPARTMENT/SCHOOL OF PLANT AND**

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**IN PARTIAL FULFILLIMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN PLANT SCIENCES AND HORTICULTURE (SPECIALIZATION: HORTICULTURE)**

**HAWASSA, ETHIOPIA**
**AUGUST, 2020**

## COLLEGE OF AGRICULTURE
## SCHOOL OF PLANT AND HORTICULTURAL SCIENCES
## ADVISORS'APPROVAL SHEET
### (Submission Sheet – 1)

This is to certify that the thesis entitled "Phenotypic plasticity and yield response of common bean (*Phaseolus vulgaris* L.) Varieties under different soil moisture levels at Hawassa, Southern Ethiopia" submitted in partial fulfillment of the requirements for the degree of **Masters of Sciences** with specialization in **Horticulture** Graduate Program of the School of **Plant and Horticultural Sciences**, College of Agriculture, and is a record of original research carried out by **Refisa Jebessa**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore I recommend that it be accepted as fulfilling the thesis requirements.

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|---|---|---|
| Amsalu Gobena (PhD) | ____________________ | __________________ |
| Name of major advisor | Signature | Date |
| Meseret Tesema (PhD) | ___________________ | __________________ |
| Name of co-advisor | Signature | Date |

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We, the undersigned, members of the board of Examiners of the final open defense by **Refisa Jebessa**, have read and evaluated his thesis entitled "Phenotypic plasticity and yield response of common bean (*Phaseolus vulgaris* L.) Varieties under different soil moisture levels at Hawassa, Southern Ethiopia" and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of masters of Science in plant and horticultural sciences (Horticulture program).

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|---|---|---|
| Amsalu Gobena (PhD) | ____________________ | __________________ |
| Name of major advisor | Signature | Date |
| Hussein Mohammed B.(PhD) | ___________________ | ______________ |
| Name of Internal Examiner I | Signature | Date |
| Walelign Worku (Prof.) | _________________ | ______________ |
| Name of Internal Examiner II | Signature | Date |
| Alemayehu Balcha (PhD) | ___________________ | _______________ |
| Name of External Examiner | Signature | Date |
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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of Graduate Studies (SGS) through the School of Graduate Committee (SGS) of the candidate's School.

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# STATEMENT OF AUTHOR

I, Refisa Jebessa, hereby solemnly and sincerely declare that, this M.Sc. Thesis is an original report of my research and that it has not been submitted, in whole or in part, for any other degree or professional qualification. I am aware of and understand the university's policy on plagiarism and I certify that this thesis is my own work. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others. This thesis has been submitted in partial fulfillment of the requirements for an M.Sc. degree at the University of Hawassa and is deposited at the university library to be made available to borrowers under rules of the library.

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Place: College of Agriculture, Hawassa University, Southern Ethiopia

Date of Submission: ______________________

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# DEDICATION

This scientific paper is dedicated to my beloved mother, Alemi Zeleke Fufa and my father, Jebessa Geleta Gerba for their constant support and love

# LIST OF ABBREVATIONS AND ACRONOMYS

| | |
|---|---|
| ABA | Abscisic acid |
| ANOVA | Analysis of Variance |
| CEC | Cation exchange capacity |
| CIAT | International Center for Tropical Agriculture |
| CSA | Central statistical agency |
| DWD | Directorate of Water Development |
| EC | Exchange capacity |
| EIAR | Ethiopia Institute of Agricultural Research |
| FAOSTAT | Food and Agriculture organization statistics |
| FC | Field capacity |
| Fv/Fm | Maximum quantum efficiency |
| FW | Fresh weight |
| LSD | Least significance difference |
| MARC | Melkassa Agricultural Research Center |
| MEQ | Milli equivalent |
| MoARD | Ministry of Agriculture and Rural Development |
| OA | Osmotic adjustment |
| PAR | Photosynthetic active radiation |
| pH | Potential hydrogen |
| PPM | Parts per million |
| PSII | Photosystem II |
| PWP | Permanent wilting point |
| ROS | Reactive oxygen species |
| Rubisco | Ribulose-1,5-bisphosphate carboxylase/oxygenase |
| RWC | Relative water content |
| SAS | Stastical Analysis System |
| UV | Ultra violet |
| VPD | Vapor pressure deficit |
| WUE | Water use efficiency |

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# ABSTRACT

Refisa Jebessa (BSc. in Horticulture)
Major Advisor: Amsalu Gobena (Ph.D.)
Co-Advisor: Meseret Tesema (Ph.D.)
School of Plant and Horticultural Sciences, Hawassa University, P.O. Box 05, Hawassa, Ethiopia

*Common bean (Phaseolus vulgaris* L.) *is an herbaceous annual leguminous plant grown worldwide for its edible dry seeds or green unripe pods. Bean is particularly suitable for food security due to its short growing cycle and adaptability to different cropping systems. However, the common bean productivity is commonly influenced by different biotic and abiotic factors. Soil moisture is one of the main environmental factors affecting growth and crop yield. A pot experiment was performed to study the effects of moisture stress on the morphological, physiological traits, and yield components of common bean varieties under shade house. The treatment comprised a factorial combination of five common bean Varieties (Hirna, kufanzik, Awash-1, Ado, Chercher) and three moisture levels (control, waterlogging stress, and drought stress) with three replication, totally 15 treatment combination was formed. The drought stress and waterlogging treatments were imposed* at 20 days after planting, as soon as the commencement of trifoliate leaves. *The result of this finding revealed that all growth parameters were significantly influenced by moisture levels; however, crop phenology influenced by the interaction effect of main factors. photosynthesis rate, transpiration rate, stomatal conductance, water use efficiency, relative water content, chlorophyll-a, chlorophyll-b, chlorophyll (a+b), chlorophyll fluorescence, pods per plant, seeds per plant, grain yield per plant and harvest index were significantly influenced by the interaction effect of varieties and moisture levels, but free proline content was increased similarly under control and drought stress. Stomata number, epidermal cell number, stomata width, and stomata length were only influenced by varieties. The result also indicated that the morphological and physiological reactions to drought stress and waterlogging stress were varies among varieties. Varieties exposed to water stress and waterlogging significantly reduced all tested parameters, except for crop phenology and proline concentration as compared to daily watering (control) treatment. Ado and Awash-1 were relatively susceptible to damage when drought stress and waterlogging stress occurred compared to Hirna, Chercher, and Kufanzik. From this study Hirna and Kufanzik Varieties were considered as tolerant as they were able to maintain their phenotypic plasticity and performed better yield compared to Chercher, Awash-1 and Ado, but Chercher variety was able to tolerate under logging stress than others, however, this study was conducted on a specific common bean variety in one season. Further research is hence needed under field condition to determine the water stress effects on a large number of common bean varieties before generalized conclusions can be drawn.*

**Keywords**: Common bean, Chlorophyll, Drought stress, Photosynthetic rate, Plasticity, Proline, Waterlogging, Yield component

## 1. BACKGROUND AND JUSTIFICATION

Common bean (*Phaseolus vulgaris L.)* is an herbaceous annual plant grown worldwide for its edible dry seeds or green unripe pods; it belongs to the Fabaceae family in the genus Phaseolus, which has about 50 species globally. The crop is highly polymorphic warm-season crop which has two growth habit: erect herbaceous bushes (determinate) up to 20 to 60 cm high and climbing vines (indeterminate) up to 2 to 5 m long (Ecocrop, 2013).

Common bean requires a considerable amount of water during its growing season to develop and produce seeds following its genetic potential (Broughton *et al.*, 2003; Rao *et al.*, 2013; Beebe *et al.*, 2013). The common bean crop is one of the most traditional foods, with significant social and economic importance, moreover, it is the most important crop legume for human consumption, accounting for 50% of the grain legumes consumed worldwide (Bastos *et al.*, 2016; (Ayra *et al.*, 2018). Bean is particularly suitable for food security due to its short growing cycle (2.5 to 3 months) and adaptability to different cropping systems (Wagara and Kimani, 2007).

In the developing world, beans are traditionally a small farmer crop, often grown in complex farming systems in association or rotation with maize, sorghum, bananas or other crops (Broughton *et al.*, 2003) Thus, beans play an essential role in the sustainable livelihoods of smallholder farmers by providing both food security and income generation and has a high potential for reducing malnutrition in poor families (Chekanai *et al.*, 2018).

In Ethiopia, common bean is mainly grown in Eastern, Southern, Southwestern, and Rift valley areas of the country (Habte *et al.*, 2014), and it is one of the fast-expanding legume crops that provide an essential part of the daily diet and foreign (Girma *et al.*, 2009).The crop grows well between 1400 and 2000m above sea level (Mekonnen, 2007). Because of its diversity in growth habit and morphology haricot bean is convenient to be grown under different cropping systems. It can be grown in sole stand or in association with other crops (Walelign, 2015). In most of the country, it is used almost in a different form; the green unripe pods are cooked or conserved as vegetable and the ripe seeds cooked for "nifro" or boiled with mixed sorghum or maize and can be consumed as "wot" using powder form (MoARD, 2009).

Even though the crop has tremendous importance in the country its yield is highly challenged by moisture stress, diseases, and insect pests (Habtu and Abiye, 2009).

Soil moisture is one of the main environmental factors affecting growth and crop yield. Plant exposed to drought or moisture stress reduces the growth and yield of various crops by decreasing chlorophyll pigments, photosynthetic rate, stomatal conductance as well as transpiration rates (Taiz *et al.*, 2015). Plants grown under drought conditions have a lower stomatal conductance to conserve water. Consequently, CO2 fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for growth and yield of plants (Mafakheri *et al.*, 2010). Severe drought stress also inhibits the photosynthesis of plants by causing changes in chlorophyll content, by affecting chlorophyll components and by damaging the photosynthetic apparatus (Becana *et al.*, 1998).

Moreover, plants exposed to moisture stress, extreme temperature, photoperiod, and interaction between factors modified the growth patterns of the plant during the growth cycle (Ramirez-Vallejo and Kelly, 1998;Beebe *et al.*, 2008). Drought reduced common bean productivity by 60% at a worldwide level and is endemic in the major production areas (Bougrier *et al.*, 1995; Emam and Seghatoleslami, 2005). Hence, as compared to other stress factors drought-induced loss in crop yield probably stronger, since both the severity and duration of the stress are critical (Jaleel *et al.*, 2009).

Common bean cultivars and lines have been responding differently to soil moisture deficit during the flowering period, depending on the severity of drought stress (Boutraa and

Sanders, 2001; Molina *et al*., 2001). Drought stress during the flowering and grain-filling periods reduced seed yield and seed weight and accelerated maturity of dry bean (Szilagyi, 2003; Zlatko, 2005).

Molina *et al*. (2001) reported that drought stress reduced grain yield of common bean cultivars, by 50%. However, Plants experiencing drought can adjust their morphology to optimize water uptake by the roots while decreasing the rate of photosynthesis by the leaves, thereby changing the production of growth and defense metabolites (Koricheva *et al*., 1998; Grant *et al*., 2005; Nicotra *et al.,* 2007; Kleine and Mueller, 2014). The combination of suitable cultivars, use of modern irrigation systems, and optimization of cultivation management practices can improve cost-effectiveness and minimize problems of water shortages with a particular emphasis on sustainable resource management and environmental protection (Saleh *et al*., 2018).

However, moisture stress is not only due to lack of water, but moisture stress can also be explained in terms of excess due to inaccessibility to root uptake. Water is chemically important, however, its certain physical properties interfere with free gas exchange and thus can injure and kill plants when they are submerged (Jackson and Ricard, 2003) or even when only the soil is waterlogged. Vegetable crops are more sensitive to waterlogging than field crops in terms of yield (Rao and Li, 2003). It has been estimated that approximately 10% of all irrigated farmland in the world suffers from frequent waterlogging, which may decrease crop productivity by 20% (Jackson, 2004).

Water deficit, caused by irregular rain distribution patterns may occur one or more times during the common bean's life cycle, including crop development phases such as the initial establishment of the seedlings, vegetative growth, flowering, and/or grain filling (Rao *et al*., 2013). Waterlogging imposes a severe selection pressure on plants principally because excess water in their surroundings can deprive them of certain basic needs notably oxygen and carbon dioxide for photosynthesis (Jackson *et al.*, 2009). Plant responses to flooding include reduced stem growth, inhibition of leaf elongation, chlorosis, reduced rates of CO2 assimilation reduced nutrient uptake and reduced root and shoot growth, the formation of aerenchyma and adventitious roots, and increased susceptibility to attack by pathogens and predators(Celik and Turhan, 2011). Although the degree varies from genotype to genotype, common bean is commonly known as a sensitive plant to water-stress conditions (Singer *et al.,* 1996). Common bean productivity significantly reduced due to waterlogging and the effect is becoming an increasingly important abiotic stress that seriously restricts crop growth (Yamauchi *et al*., 2018).

However, plants have diverse mechanisms for response and adaptation to water stress. Therefore, the determination of their distinct morphological, physiological, and agronomic traits for drought tolerance is indispensable to ensure efficiency in the selection process (Beebe *et al*., 2013). An early morphological response to drought stress is the avoidance mechanism through adjustment of plant growth rates such as a reduction in shoot height, basal diameter, and total fresh/ dry mass in the bean species (Lei *et al*., 2006; Kusvuran *et al*., 2011).

Root architecture can allow deeper and moister soil layers to be exploited to escape from water deficit, and thus it can be a promising trait for crop performance under stress conditions (Vadez, 2014). In the other way, plants have evolved various physiological and metabolic responses to individual stresses, but the nature of such responses strongly depend on whether and how stresses co-occur in the plant’s environment (Atkinson and Urwin, 2012; Suzuki *et al*., 2014; Nguyen *et al*., 2016).

Some of the mechanisms for the oxygen-deprived condition of plants are shifting their metabolism to anaerobic from the aerobic mode. Plants, which can withstand waterlogging conditions, have mechanisms such as increased availability of soluble sugar, aerenchyma formation, greater activity of glycolytic pathway and fermentation enzymes, and involvement of antioxidant defense the mechanism to cope with the oxidative stress induced by waterlogging (Ahmed *et al*., 2012).

Root architecture and plasticity play an important role in the adaptation to submergence and waterlogging stress. The formation of aerenchyma and adventitious roots is a morphological characteristic of waterlogging-tolerant species (Fukao *et al.,* 2003). Aerenchyma is known to enhance internal oxygen diffusion from the aerial parts to the waterlogged roots that allow the roots to maintain aerobic respiration (Armstrong, 1980).

Similarly, drought resistance mechanisms in plants are also varying based on the potential and sensitivity of plants. Some plants avoid water stress by sustaining of important physiological processes such as stomata regulation when exposed to mild drought, some plants tolerate by osmotic adjustment and osmoprotectants and others regulate growth period to avoid moisture stress; termed as drought escape (Fang *et al*., 2015; Luo, 2010; Manavalan *et al*., 2009).

Physiological aspects, such as lower stomatal conductance, are also considered to be mechanisms of adaptation to water shortage, allowing the plant to reduce evapotranspiration area (Beebe *et al*., 2013; Rao, 2014). Other important traits are partitioning of dry matter to promote grain production, and harvest index (Rao *et al*., 2013).

In developing higher-yielding crops, physiological understanding and phenotyping of specific traits will likely be useful to screen genotype that fit moisture stress environments.

Development of common bean genotypes that are adapted to different scenarios of drought conditions can help to increase the available knowledge regarding the behavior of common bean genotypes to climate change. Techniques to facilitate the identification of drought-tolerant genotypes have become important in modern agriculture (Todaka *et al.,* 2015).

However, the mechanism of how common bean varieties are adapting to different moisture levels is not well addressed. Therefore, this study was focused to evaluate phenotypic variability, physiological traits, and morphological responses of common bean varieties under different soil moisture levels and to determine the relationship between these traits and yield components. The work provides information on how locally adapted and released common bean varieties respond to different moisture stress and to identify tolerant and sensitive varieties for further studies.

### 1.1.General objectives

- To investigate the impact of different levels of soil moisture stress on morpho-physiological and yield components of common bean varieties

### 1.2. Specific objectives

- To identify common bean varieties those are tolerant to moisture deficit and waterlogging
- To study morphological and physiological adaptation mechanism that common bean variety used to grow under water deficit and waterlogging condition
- To determine yield response of common bean varieties under different soil moisture levels

# 2. LITERATURE REVIEW

## 2.1. Botany of common bean

All bean genotypes generally originated from two gene pools; the Andean (typically large-seeded) and the Mesoamerican (small-seeded) gene pools. Common bean belongs to genus Phaseolus, species vulgaris, family Leguminosae, subfamily Papilionoideae, tribe Phaseoleae, sub-tribe Phaseolinae. Common beans are further classified into the dry bush type, which is the most widely cultivated, and the climbing bean type, a recent innovation with high yielding potential. The crop is the most widely grown, occupying more than 85% of the production area sown to all Phaseolus species in the world (Singh, 2001).

Common bean represents a wide range of life histories (annual to perennial), growth habits (bush to climbing), reproductive systems, and adaptations (from cool to warm and dry to wet). Common bean shows the variation in growth habits that could be bushy determinate, bushy indeterminate, prostrate indeterminate and extreme climbing indeterminate types (Buruchara, 2007).

## 2.2. Importance of common bean

Common bean is the most important food legume in the world (Broughton *et al*., 2003). The crop provides protein, complex carbohydrates, and valuable micronutrients for more than 300 million people in the tropics and is a staple crop for over 200 million people in sub-Saharan Africa (Akibode *et al*., 2011). Nutritionally, the common bean has high protein content with a good source of energy and it provides folic acid, dietary fiber, and complex carbohydrates (Dagnew *et al*., 2014). Beans are also a valuable source of vitamin B complex, iron, zinc, sulfur, and other essential minerals (Beebe *et al*., 2000). Also, common bean protein is high in lysine, which on the other hand is relatively deficient in maize, cassava, and rice, making it a good dietary complement to these staples (Katung *et al.*, 2009). Common bean, therefore, plays an important role in mitigating protein malnutrition and micronutrient deficiencies in regions where their effects are prevalent. Typically, beans planted for vegetable use are planted in monoculture (Singh and Schwartz, 2010; Wortmann, 2006). Because bean varieties consumed as a vegetable produce pods in as little as two months, rotations with other crops is a common practice (Broughton *et al*., 2003).

Furthermore, epidemiological studies also have shown that a regular diet with beans brings great benefits to health since it reduces the risk of developing cancer, diabetes, and heart disease (Guajardo-Flores *et al*., 2013).

Common bean ranks third as an export commodity in Ethiopia and contributing about 9.5% of the total export value from the agricultural income of the country (FAOSTAT, 2015). Bean products are consumed at various stages of plant development, and thus, offer a staggered and prolonged food supply in the form of leaves, green pods, fresh grains, dry grains, as well as bean composite flour for Porridge and other snacks.

Agriculturally, Common bean is also important in providing fodder for feeding livestock and it contributes to soil fertility improvement through atmospheric nitrogen fixation during cropping season (Asfaw and Blair, 2014; David, 2016). Besides its high nutritional values the crop also contributes to the stability of farming systems in Ethiopia (Asfaw and Blair, 2014). Beans bring to cropping systems the crucial capacity to decrease or eliminate the need for direct applications of nitrogen fertilizer.

## 2.3. Status of common bean production Ethiopia

Common bean is mostly grown in small and medium-sized farms due to the small landholding of most of the farmers in Ethiopia. In Ethiopia, It’s grown predominantly under smallholder producers as an important food crop and source of cash. It is one of the fast-expanding legume crops that provide an essential part of the daily diet and foreign earnings for most Ethiopians (Girma, 2009). A nationally coordinated research in Ethiopia began in the early 1970s by the Melkassa Agricultural Research Center (MARC). So far, a large number of common bean germplasm were introduced and evaluated for adaptation and productivity (Legesse *et al*., 2006). The Ethiopian national common bean improvement program has been trying to release promising bean varieties through crop improvement techniques (CIAT, 2008).

## 2.4. Common bean production constraints in Ethiopia

Production of common bean is highly constrained by environmental stresses such as drought, pests, diseases, and low input farming methods that have resulted in declined soil fertility and productivity (Asrat *et al*., 2013).

In major common bean producing areas of Ethiopia, production is generally trending upwards. Both area and yield have been growing at a positive average rate since 2002 in response to economic reforms of the 1990s (Legesse *et al*., 2006; Alemu and Bekele, 2005). However, the national average yield of 900 kg ha-1 for 2007 is too low compared to recent report of 1.43 for 2016 and 1.62 for 2017(CSA, 2017)

## 2.5. Agro-ecology of common bean

Common bean is adapted to a wide range of climatic conditions ranging from sea level to nearly 3000 meters above sea level (m.a.s.l.) depending on the variety. However, it does not grow well below 600 meters due to the poor pod set caused by high temperatures (Dev et al., 1997). It grows best in a warm climate at a temperature range of 18°C to 24°C (Assefa *et al.*, 2005). Mekonnen (2007) suggested that a common bean grows well between 1400 and 2000 m.a.s.l. Moreover, common bean performs best on deep, friable, and well-aerated soil types with an optimum pH range of 6.0 to 6.8. The major common bean producing areas of Ethiopia are central, eastern, and southern parts of the country (CSA, 2016).

## 2.6. Effect of drought stress on growth and development of common bean

Drought stress has also been proved to be a very important limiting factor at the initial phase of plant growth and establishment through its effects on both elongation and expansion growth (Anjum *et al.*, 2003; Shao *et al.*, 2008). This is due to low turgor pressure which suppresses cell expansion and growth leading to significant reductions in fresh and dry biomass production (Farooq *et al.*, 2009). Drought stress is also associated with accelerated maturity, although late-season release from stress may result in delayed maturity (Singh, 1995).

The effects of drought stress vary depending on the frequency, duration; intensity of stress, growth stages affected and can be amplified by other stresses such as poor soils, disease, and heat (Tilahun *et al.*, 2004; Muñoz- Perea *et al.*, 2007; Ambachew *et al.*, 2015). In common bean, excessive abortions occur during pre-flowering and reproductive periods during drought stress (Nielsen and Nelson, 1998). Thus, the growth stages as affected by the intensity and duration of drought determine the extent of losses in seed yield and quality (Abebe *et al*., 2013).

## 2.7. Physiological responses of plants to drought stress

Drought typically occurs as a result of low and non-frequent precipitation, resulting in reduced soil water content that is first detected by plant roots (Silva *et al*,. 2013). Depending on drought duration and severity the water status of plants can be affected by insufficient water absorption due to low soil water availability, as well as to increased water loss in the process of transpiration. Water deficit in plants affects their normal physiological processes and hinders the development, growth, and yield, ultimately resulting in wilting, senescence, and plant death (Silva *et al*, .2013).

Drought stress is an important limiting factor in the initial phase of plant growth and establishment affecting both elongation and expansion growth (Anjum *et al*., 2003; *Shao et al*., 2008). This is due to low turgor pressure which suppresses cell expansion and growth leading to significant reductions in fresh and dry biomass production (Farooq *et al*., 2009). Severe water stress may result in the arrest of photosynthesis, disruption of metabolism and cell structure, and eventually the cessation of enzyme-catalyzed reactions, with the eventual death of the plant. Accordingly, specific effects of water stress vary depending on the previous history of the crop, phenological stage, and duration and intensity of the stress (Jaleel *et al*., 2009). Physiological responses to drought stress include loss of turgor pressure (Tardieu *et al*., 2014), decrease in stomatal conductance or stomatal closure, reduced leaf water potential, recognition of root signals, a decline in net photosynthesis and reduced growth rates (Xu *et al*., 2010). According to Ashraf and Harris (2013), the effects of drought stress on photosynthesis are attributed to two major components i.e.

reduced gas exchange and loss of efficiency in the physiological processes of photosynthesis.

Most commonly responses of common bean to drought stress, include rooting pattern (Beebe *et al*., 2013), the capacity to partition a greater proportion of carbohydrates to seed under stress (Subbaro *et al*., 1995; Singh *et al*., 2007), reduced stomatal conductance and leaf area, and the capability to maintain turgor through osmotic adjustment (Tilahun *et al*., 2004; Beebe *et al*., 2013).

The response to drought in different common bean genotypes has been characterized in several studies based on physiological measurements such as photosynthesis and photosynthetic acquisition as well as on partitioning indices (Costa *et al*., 2000).

Photosynthesis and cell growth are primary processes influenced by drought due to decreased stomatal conductivity in the early drought phases that limit evaporation and CO2 diffusion in the leaf mesophyll. The surplus energy on the thylakoids in the photosynthesis apparatus result in photoinhibition—reduced photochemical efficiency (Chaves *et al*., 2002).

The chlorophyll fluorescence technique has become important in plant ecophysiological studies because photosystem II (PSII) is sensitive to water deficit (Maxwell and Johnson, 2000). Drought responsive traits have been studied in common bean by evaluating various traits in field experiments as well as in more controlled environments, such as, green house (Polania *et al*,. 2016).

### 2.8. Effect of waterlogging stress in plants

The main cause of damage under waterlogging is oxygen deficiency, so the plants show wilting even when enclosed by an excess of water, which affects nutrient and water uptake (Sairam *et al*., 2008). Plants tolerant to waterlogging stress exhibit certain adaptation, such as the formation of aerenchyma and adventitious roots. The formation of aerenchyma is considered as an adaptive response of the plant under flooding stress (Evans, 2004). Furthermore, due to the interaction of plant hormones, auxin, and ethylene the formation of adventitious roots takes place (Crawford *et al*., 2003). Waterlogging induced several physiological disturbances in growth, dry matter, photosynthesis and pod formation that resulted in lower yield (Solaiman *et al*., 2007; Pociecha *et al*., 2008; Celik and Turhan, 2011; Hasanuzzaman *et al.,* 2016). Waterlogging reduced seed yield primarily by reducing the number of pods per plant and pod setting (Ahmed *et al*., 2002).

One of the first plant responses to waterlogging is the reduction in stomata Conductance (Folzer *et al*., 2006). Low levels of O2 may decrease hydraulic conductivity due to hampered root permeability (Else *et al*., 2001).

Oxygen deficiency generally leads to a substantial decline in the net photosynthetic rate (Ashraf *et al*., 2011). This decrease in transpiration and photosynthesis is attributed to stomatal closure (Ashraf and Arfan, 2005). However, other factors such as reduced chlorophyll contents, leaf senescence, and reduced leaf area are also held responsible for decreased rates of photosynthesis (Malik *et al*., 2001). However, plants exhibit a certain adaptation under waterlogging stress to maintain photosynthetic capacity (Li *et al*., 2004).

Chlorophyll fluorescence is an excellent physiological marker that determines the primary processes involved in photosynthesis such as energy transfer due to excitation, absorption of light, and photochemical reactions occurring in the PSII (photosystem II) (DeEll *et al*., 1999; Saleem *et al*., 2011). The plants subjected to waterlogged conditions exhibit certain alterations in this physiological marker, and a prominent decrease in maximum quantum efficiency (Fv/Fm) was recorded (Hua *et al*., 2006). Likewise, a decrease in the maximum quantum yield of PS II photochemistry (Fv/Fm) was also recorded in field beans when subjected to varying days of waterlogging stress (Pociecha *et al*., 2008).

PSII photochemistry was also impaired due to waterlogging in the Medicago sativa.

The decrease in Fv/Fm indicated the sensitivity of the photosynthetic apparatus to abiotic stress and also the inability of the plants to regenerate rubisco under stressful conditions (Smethurst *et al*., 2005).

### 2.9. Waterlogging and drought effect on plants roots

Through roots plants take minerals and water to maintain life and struggle for nutrition. When plants are grown underwater or salt stress, the competition is more distinct and roots describe the tolerance of plants against stress (Raiz *et al*., 2013). Roots in waterlogged soils frequently die of anoxia (oxygen deficiency). Most trees and shrubs cannot grow for long in waterlogged soil (Halcomb, 2003) roots, suffer hypoxia or anoxia. Moreover, aerenchyma, which thought to contribute to waterlogging tolerance, is developed in the cortex of new and existing roots of some plant species. In the rice crop the aerenchyma well developed and adopt flooded conditions (Tepwadee, 2008).

Aerenchyma and adventitious root development in soybean have been observed after 1 d of water-logging stress (Thomas *et al*., 2005). Oxygen deficiency inhibits the root respiration of plants, which results in a considerable reduction in energy kind of root cells. Since in the absence of oxygen terminate electron acceptor in aerobic respiration, also Kreb’s cycle and electron transport system are blocked (Ashraf and Harris, 2013).

Drought stress severely inhibits plant growth, however; the development of shoots is usually more affected than that of root under drought. Plants that escape water deficit develop large root and maximize their water uptake to complete their life cycle rapidly (González *et al*., 2006).

## 2.10. Drought adaptation mechanisms in plants

Plants use different mechanisms to cope with drought stress such as; drought tolerance, drought escape and drought avoidance

### 2.10.1 Drought tolerance

Drought tolerance is the ability of a crop plant to produce its economic product with minimum loss in a water-deficit environment relative to the water constraint-free environment (Mitra, 2001). Furthermore, drought tolerance is the ability of plants to withstand water-deficit with low tissue water potential (Chalves *et al*., 2003; Mitra, 2001). Plants can also tolerate drought stress conditions by avoiding dehydration of tissues and maintaining high tissue water potential or tolerating low tissue water potential by minimizing water loss and maximizing water uptake (Chaves *et al*., 2003). Plants that use tolerance mechanism maintain turgor through osmotic adjustment through an accumulation of compatible solutes in the cell, increase cell elasticity, decreased cell volume, and resistance to desiccation (Agbicodo *et al*., 2009). However, plants may use more than one mechanism at a time to cope with drought (Agbicodo *et al*., 2009). Proline and amino acid are involved in osmotic adjustment (OA) and protection of cells during dehydration (Zhang *et al*., 2009).

A growing body of evidence indicated that proline content increases during drought stress and proline accumulation is associated with improvement in drought tolerance in plants (Seki *et al*., 2007; Zhang *et al*., 2009).

During drought stress, proline plays an important role and acts as a signaling compound to regulate mitochondria function and affect cell proliferation through activating particular genes, which are essential for stress recovery (Solanki and Sarangi, 2015). Adaptation of common bean to different environmental conditions around the world and apparent genetic diversity for stress tolerance makes it an excellent crop model plant (Gómez, 2004).

### 2.10.2. Drought escape

Drought escape is the ability of a plant to complete its life cycle before serious soil and plant water deficits occur. This mechanism involves rapid phenological development (e.g. early flowering and early maturity), developmental plasticity (variation in the duration of growth depending on the extent of water deficit), and remobilization of photo assimilates (Chaves *et al*., 2003). Flowering time is an important trait related to drought adaptation, where a short life cycle can lead to drought escape (Araus *et al*., 2002).

Drought escape occurs when phenological development is successfully matched with periods of soil moisture availability, where the growing season is shorter and terminal drought stress is prevalent (Araus *et al*., 2002). Developing short-cycle varieties has been an effective strategy for minimizing yield loss from terminal drought, as early maturity helps the crop to avoid the period of stress (Farooq *et al*., 2009).

### 2.10.3. Drought avoidance

Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture. Mechanisms for improving water uptake, storage in a plant cell, and reduction in water loss confer drought avoidance while responses of plants to tissue deficit determine drought tolerance (Mitra, 2001). Plants develop strategies for maintaining turgor by increasing root depth or developing an efficient root system to maximize water uptake, and by reducing water loss through reduced stomatal conductance, reduced absorption of radiation, by leaf rolling or folding, and reduced leaf area (Turner, 1986; Mitra, 2001). The root characters such as biomass, length, density, and depth are the main drought avoidance traits that contribute to the final yield under terminal drought environments (Subbarao *et al*., 1995).

## 2.11. Effect of moisture stress on yield and yield component of common bean

Water stress during the reproductive development of a crop is usually associated with a large decrease in yield via biomass and/or distribution of dry matter in different parts of the plant (Beshir *et al*., 2015). According to Polania *et al*. (2016) drought is the second most important factor in yield reduction after diseases. Drought stress during flowering and seed formation stages decreased bean yield (Boutraa and Sanders, 2001; Beshir *et al*., 2015).

Direct selection for yield under favorable or water-limited conditions is the selection strategy that has been the most commonly used by crop breeders to improve yield in water-limited environments (Tilahun *et al*., 2004). Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress. Drought stress affects the yield components such as the number of pods per plant, number of seeds per pod, seed weight, and harvest index (Ambachew *et al*., 2015; Darkwa *et al*., 2016). It was noted that post-flowering heat stress caused yield losses of up to 50% due to reduced seed filling duration (Bernier *et al*., 2007; Beebe *et al*., 2013).

Waterlogging is more common and often causes considerable yield loss across plant species. According to Richee (2004) waterlogging stress can reduce soybean yield by up to 43% during the vegetative growth stages and 56% during the reproductive stage. Waterlogging during the vegetative and the early reproductive stage is more damaging to grain yield than other stages (Toai *et al*., 2010). The extended duration of waterlogging resulted in a significant yield reduction (Ren *et al*., 2014).

# 3. MATERIALS AND METHODS

## 3.1. Growth condition and plant material

A shade house study was carried out from September 2019 to December 2019 at Hawassa University College of Agriculture located in the city of Hawassa at an altitude of 1708m.a.s.l (7°3′N and 38°28′E). The area is located in the Sidama region in Southern Ethiopia, which is 275 km far away from Addis Ababa, the capital city of Ethiopia.

The shade house used for the experiment was fenced with metal wire and the roof was covered by transparent polycarbonate.

For this experiment, five released common bean varieties were brought from Haramaya University. Chercher and Hirna were determinate bush, whereas Ado and Awash-1 were determinate semi-climbing. Kufanzik was Indeterminate climbing, and the detailed information was given below (Table 1)

Table 1**.** Common bean varieties used for the experiment

| **Nº** | **Variety** | **Pedigree** | **Seed color** | **Released by** | **Year released** |
|---|---|---|---|---|---|
| 1 | Chercher | ATTT-165-96 | White | HU | 2006 |
| 2 | Ado | SAB-736 | White | MARC | 2014 |
| 3 | Kufanzik | MX-8754-9M | Pinto | HU | 2008 |
| 4 | Awash-1 | Extrico-23 | White | MARC | 1990 |
| 5 | Hirna | ECAB-0203 | Red | HU | 2012 |

Where, MARC is Melkasa Agricultural Research Center, HU is Haramaya University

### 3.2. Experimental design and treatments

The pot experiment was set out as a completely randomized design arranged as a factorial combination of moisture levels x varieties with three replications. The main treatment comprised three moisture levels (control, waterlogging and drought stress) and five common bean varieties (Chercher, Ado, Kufanzik, Awash-1, and Hirna) in a 5 x 3 factorial scheme, formed fifteen treatment combination with three replications (45 experimental units) (Table 2). Twelve plants per experimental unit were considered as one replication. For effective utilization of irrigation water and optimum growth of common bean cultivars, 75% FC water treatment level was advisable (Abiot Molla, 2018). One seed of common bean varieties was planted into a perforated plastic pot of 22 cm in length and 16 cm in diameter filled with sun-dried composite soil. Actual moisture treatment was imposed at 20 days after planting, as soon as the commencement of trifoliate leaves. During the experimental period plants received tap water manually along with required cultural practices. During the late seed filling, watering was stopped as it is known to promote more vegetative growth at the expense of reproductive growth in common bean (Beebe *et al.*, 2013). The meteorological data such as; air temperature, leaf temperature, and relative humidity were recorded.

Table 2**.** Description of the experimental treatments

| **Moisture levels** | **Varieties** | **Description of treatments** |
|---|---|---|
| Control | Chercher<br>Ado<br>Kufanzik<br>Awash-1<br>Hirna | The pots in the treatment were watered daily to control the soil moisture at optimum |
| Waterlogging stress | Chercher<br>Ado<br>Kufanzik<br>Awash-1<br>Hirna | Each pot was placed on a saucer (bowl) to hold the drained water through the bottom of the pot, and the water was maintained at 2 to 3cm above the soil throughout the experimental period (Flooded) |
| Drought stress | Chercher<br>Ado<br>Kufanzik<br>Awash-1<br>Hirna | Pots were watered within the interval of five days at the first wilting appearance to control the treatment to wilting stress |

### 3.3. Properties of the experimental soil

Experimental soil was prepared for Laboratory Analysis. Samples were collected at 0-30 cm depth by auger from different spots of the trial site (Agricultural College). The composited samples were dried and grounded to pass through 0.2 mm sieve before laboratory analysis, and the samples were analyzed for parameters relevant to the study at Hawassa soil laboratory. Soil analysis was made as per the normal laboratory procedure. The soil pH values were determined in soil water suspension 1:2.5 using glass electrode pH meters Jackson (1967). Determination of particle size distribution (texture) was carried out hydrometrically Day (1965). Based on the oxidation of organic carbon with acid potassium dichromate, Organic matter content was determined using Walkely’s and Black methods respectively (Jackson, 1967). Total N was determined as mentioned by Bremner

(1965). The chemical and physical properties of the soil before planting are presented in Table 3.Common bean prefers well-drained, sandy clay, or sandy loam soils, with balanced fertility and moderate acidity pH 5.8-6.5 (Liebenberg, 2009). Common bean performs best on deep, friable, and well-aerated soil types with an optimum pH range of 6.0 to 6.8.

**Table 3**. Physical and some chemical characteristics of experimental soils

| **Nº** | **Properties** | **Obtained Values** |
|---|---|---|
| 1 | Sand (%) | 76 |
| 2 | Clay (%) | 6 |
| 3 | Silt (%) | 18 |
| 4 | Class | Sandy loam |
| 5 | Organic carbon (%) | 4.67 |
| 6 | Total nitrogen (%) | 0.26 |
| 7 | Available phosphorus (ppm) | 13 |
| 8 | pH-(H2O) | 7.54 |
| 9 | pH-(KCL) | 6.62 |
| 10 | EC(µs) | 5.04 |
| 11 | CEC(MEQ/100gsoil) | 35.73 |
| 12 | FC (%) | 32.67 |
| 13 | PWP (%) | 22.1 |

## 3.4. Data collection and measurement

### 3.4.1. Meteorological data

**Leaf temperature**

The daily leaf temperatures were recorded three times a day (morning (6:00 am-8:00 am), midday (12:30 pm-1:30pm) and evening (5:30 pm-6:00 pm) on randomly selected 10 days using infrared thermometer during the experimental period from October to January 2019. The average value of 10 days measurements for each treatment was represented by Fig 1.

**Air temperature and relative humidity**

Temperature and relative humidity data were recorded on randomly selected days using mini data loggers (Testo 174, Version 5.0.2564.18771, Lenzkirch, Germany). The data logger was hanged closer to the plant canopy (30cm above the ground) for each treatment and covered from the top with a flat carton to avoid direct sun and moisture. The vapor pressure deficit of the shade house was calculated based on the temperature and relative humidity recorded using VPD-Auto grow software (www.autogrow.com/wp content/uploads/2016/ 03/VPD_HDCALC.xls). Data were measured every hour for 24 days.

### 3.4.2. Crop Phenology

**Days to Emergence (count):** It was determined by counting the number of days taken from planting to the emergence of 50% per experimental unit

**Days to Flowering(count):** It was recorded by counting the number of days taken from planting to when 50% of the plants per experimental unit had the first open flower

**Days to Pod Formation (count):** Days to pod formation was recorded by counting the number of days from planting to when 50% of the plants per plot had the first pod

**Days to physiological maturity(count):** It was determined as the number of days from date of planting to the date when 90% of the plants in each experimental unit attained physiological maturity when the pods had lost their green pigmentation (Beebe *et al.*, 2013)

### 3.4.3. Growth and morphological data

**Plant height (cm):** The average plant heights of five randomly taken plants from each experimental unit were measured from the ground level to the tip of the main stem at physiological maturity.

**Leaf Area (cm2):** The leaf area was measured using in $cm^2$, by the LI-COR leaf area meter at the mid of pod filling stage from all leaves of three selected plants per experimental unit

**Leaf fresh weight (g):** It was measured using sensitive balance at the mid-pod filling stage from all leaves of three selected plants per experimental unit

**Leaf dry weight (g):** It was measured by electronic sensitive balance after the samples had been oven-dried (48 hr at 75℃).

**Leaf Number (count):** All leaves of five plants per experimental unit were counted at mid pod filling stage

**Internode Length (cm):** Average internode length was measured from the main stem of randomly selected five plants at pod setting time

**Root length (cm):** Average tap root length was measured from randomly selected five plants of each experimental unit at the seedling stage before flowering after root was carefully separated from the pot and washed

### 3.4.4. Physiological data

#### Leaf gas exchange parameters

Photosynthetic gas-exchange rates were measured using a Li-6400 portable photosynthesis system (LICOR Inc., Lincoln, NE, USA). Photosynthesis (A), Stomata conductance (gs), and transpiration rate (E) were measured at 20 days after actual moisture treatment was imposed on fully developed intact leaves. Measurement was done between 10:00 AM and 11:30 AM by maintaining the following adjustments: Leaf surface area was 6.25cm$^2$, ambient carbon dioxide concentration 386 µmol mol$^{-1}$, leaf chamber mass flow rate was 250 µmol s$^{-1}$, atmospheric pressure 840 bar and photosynthetic active radiation (PAR) was manually fixed to 800 µmol m$^{-2}$ s$^{-1}$. Water use efficiency was determined as the ratio between net CO2 assimilation rate (A) and transpiration rate (E) (Bertolde *et al*., 2012).

#### Determination of leaf chlorophyll concentration

Leaf chlorophyll concentration was measured at the mid-pod fill stage on fully expanded young leaves of three plants in each experimental unit. Sampling was done at 8:00 AM and leaves were placed in a bag sealed with aluminum foil and transported to the laboratory of crop physiology. Fresh leaf discs (0.5g) were placed in 15-mL tubes containing 80 %( v/v) acetone and homogenized with acetone using a pestle and mortar. The homogenized sample mixture was centrifuge for 10,000 rpm for 15min at 40℃. The supernatant was separated and 0.5ml of each concentration level was analyzed in triplicate for Chlorophyll-a and Chlorophyll-b at an absorbance of 663nm and 646nm wavelength region, respectively, in spectrophotometer UV-2450 spectrophotometer (Hitachi, Tokyo, Japan).

The following equations were used for the quantification of Chlorophyll-a, Chlorophyll-b (Lichtenthaler and Buschmann, 2001).

Ch a (µg/ml) =12.25 ($A_{663}$) – 2.79 ($A_{646}$)

Ch b (µg/ml) =21.50( $A_{646}$)– 5.10 $A_{663}$)

Total chl (µg/ml) =chl a+chl b

Where; A = Absorbance, Ch a = Chlorophyll a, Chb = Chlorophyll b

### Determination of leaf chlorophyll fluorescence

To evaluate the performance of the plants, maximal photosystem II efficiency (Fv/Fm) of well-developed leaves at third node from randomly selected vegetative plants at age of thirty days after planting( ten days after the start of the treatment). Measurement was done using a Handy-*PEA* fluorimeter (Hansatech, Kings Lynn, UK) following the methodology of (Strasser *et al.*, 2004). Before measurement, leaves were dark-adapted in the leaf clip for 30 min. Light was then provided by an array of three high-intensity light-emitting diodes and adjusted to 1500 µmol $m^{-2}$ $s^{-1}$ to ensure that the photosynthesis was saturated during the measurements.

### Determination of Proline concentration

At pod filling stage leaf samples from each experimental unit were collected for determining proline content using the method of Bates et al., (1973). First, 50 mg fresh leaf samples were placed in 1ml of ethanol and allowed to overnight at 4℃; following day the samples were centrifuged at 14000g for 5minutes. 100µl of reaction mix [(1% ninhydrin (w/v)+60% Glacial acetic acid(v/v)+20%ethanol(v/v)] was pipetted to each and the sample was heated at 95℃ for 20 minutes. After cooling at room temperature the supernatant was centrifuged down quickly (1min.2500rpm). Then 100µl of the supernatant was transferred to a microplate reader and quantified at 520nm using Multisken FC. Proline concentration was determined using a calibration curve and expressed as µg/g leaf fresh weight.

### Stomata anatomy and microscopic array

Stomata anatomy measurement was made using the protocol proposed by Xu and Zhou (2008) at 60 days after the start of the treatment. A thin layer of transparent nail polish was uniformly stained on the lower surface of fresh intact leaves and waited for 10 minutes until the nail polish dried to capture the epidermal imprint of the leaves, thereafter, a thin layer covering a surface on the leaves were peeled off using transparent tape and attached on the microscope slide. The resulting molds were then examined using Automated Upright Leica Microscope DM5000 B with a 40x magnification lens fixed with a digital Leica DFC425/DFC425C image processing camera. For each sample, stomata number (per mm$^2$), epidermal cell number (per mm$^2$), stomata width (µm), and length (µm) were measured. Stomata density was expressed as the stomata number per leaf area unit (in mm$^2$).

### Relative leaf water content

Three fully expanded leaves were collected from three representative plants and leaf disks(9mm in diameter) were immediately weighed (leaf fresh weight), thereafter the samples were immediately hydrated to full turgidity for 24 h by immersing in deionized water in a closed 15-ml tube under room temperature. Afterward, hydrated samples were well dried with filter tissue paper and reweighed to obtain fully turgid mass (leaf turgid weight). Samples were oven-dried for 24 h at 75°C to obtain dry mass (leaf dry weight). Relative water content (RWC) was calculated following the method developed by Turner. (1981).

$$RWC(\%) = \left[\frac{Leaf\ fresh\ weight - Leaf\ dry\ weight}{Leaf\ turgid\ weight - Leaf\ dry\ weight}\right] x100$$

### 3.4.5. Yield components

All yield and yield component parameters were collected at physiological maturity, when 90% of the pods had lost their green color and changed their color from green to yellow (Munoz-Perea et al., 2006). Five plants per experimental unit were used

**The number of pods per plant:** The Average numbers of pods per plant were determined by counting pods of the five randomly selected plants per experimental unit.

**The number of seeds per plant:** Average number of seeds per plant of five randomly selected plants was determined

**Grain yield (g/plant):** The average grain yield in gram was measured from five randomly taken plants in each experimental unit after seed moisture was corrected to 10 %

**Harvest Index (%):** Was determined as the ratio of grain yield to the above-ground biomass

## 3.5. Statistical Analysis

All collected data were elaborated statistically using analysis of variance (ANOVA) performed using SAS software package (SAS version 9.2, 2008). Means were separated on the basis of Fisher's protected LSD test ($P \leq 0.05$). Pearson correlation analysis was used to define the relationship between various variables.

# 4. RESULT AND DISCUSSION

## 4.1. Meteorological data

### 4.1.1. Leaf temperature

The average maximum and minimum temperature were 26.22°C and 18.67°C, from mid-day and morning, respectively (Fig.1). Leaf temperature during midday was high (above 25$^{o}$C), whereas, leaf temperature during morning was declined (below 20$^{o}$C) during the experiment.

Changes in leaf temperature can be induced by water loss due to transpiration. Therefore, changes in the leaf water content and transpiration can be indirectly reflected by changes in leaf temperature. Drought stress (water stress) treatment raised the leaf temperature in all varieties. The result is in agreement with the finding of Khan *et al*. (2007) who reported that water stress resulted in considerable increases in leaf temperature.

The result suggests that relative water content was significantly and positively correlated with morning temperature(r=0.93), mid-day temperature (r=0.98) and Evening temperature(r=0.97). Similarly, Liu *et al*. (2014) reported that there is a certain correlation exists between the leaf water content and leaf temperature. Photosynthesis is the most sensitive of plant cell processes to high temperatures (Sharkey and Schrader, 2006), which causes changes in the reduction-oxidation properties of PSII acceptors and reduces the efficiency of photosynthetic electron transport in both photosystems (Mathur *et al*., 2014).

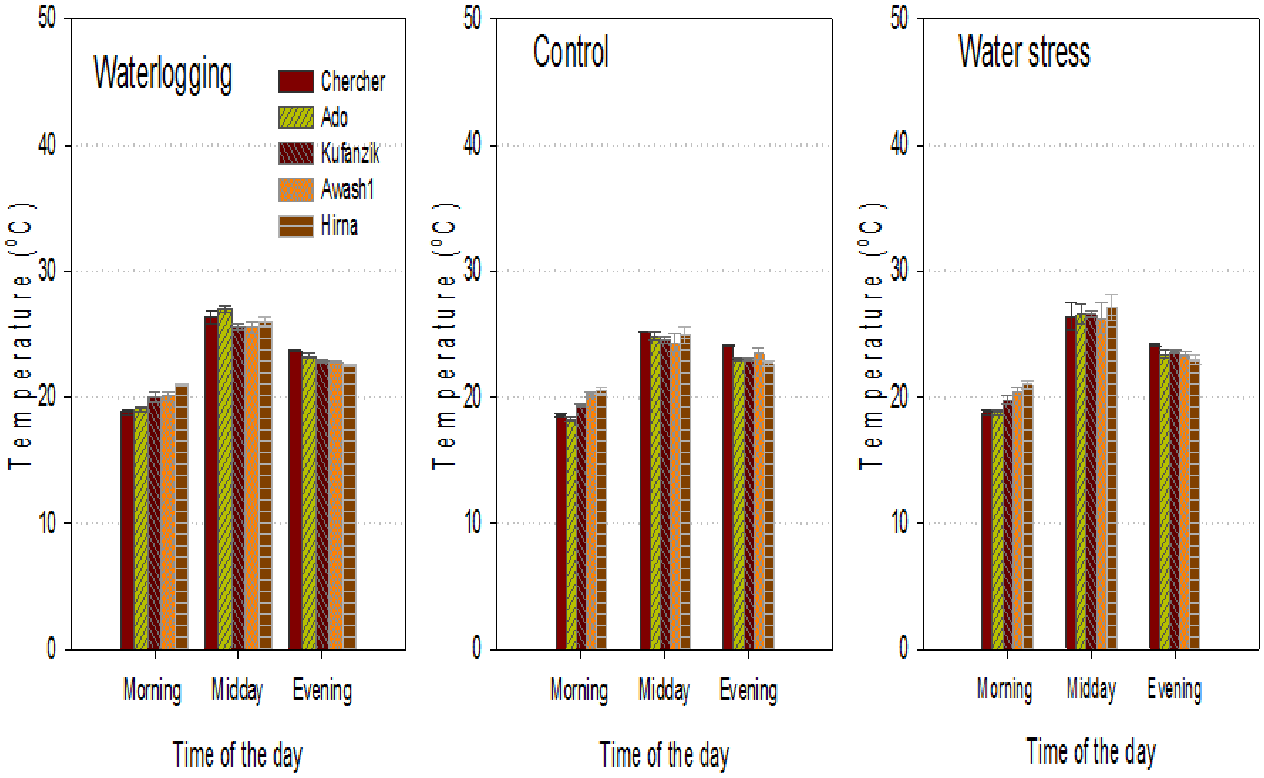

Figure 1. Effect of different time of the day on leaf temperature of five common bean varieties grown under different soil moisture level from September 2019 to December 2019.

### 4.1.2. Air temperature and relative humidity

From the result, it was observed that extremely higher (37.00°C) and lower (13.20°C) temperature were recorded during the middle of the day (12:18 pm) and before dawn (5:18 am), respectively (Table 4). Report from (Assefa *et al.*, 2005) indicated that common bean grows best in a warm climate at a temperature range of 18°C to 24°C. Regarding relative humidity, shade house daily maximum relative humidity (93.33%) was recorded at 5:18 am (night before dawn) which was coincided with shade house minimum temperature (13.20°C) and minimum vapor pressure difference (0.10KPa).

Likewise, shade house daily minimum relative humidity (28.8%) was recorded at 12:18 pm which coincided with maximum daily temperature (37.00%) and maximum daily vapor pressure deficit (4.16KPa).

Table 4. Air temperature and relative humidity of the common bean canopy under Shade house.

| **Hours** | **Temperature** | **RH%** | **VPD (KPa)** |
|---|---|---|---|
| 5:18:00 PM | 22.35 | 58.03 | 1.13 |
| 6:18:00 PM | 20.7 | 66.36 | 0.82 |
| 7:18:00 PM | 20.15 | 65.2 | 0.82 |
| 8:18:00 PM | 18.25 | 75.16 | 0.52 |
| 9:18:00 PM | 17.15 | 80.06 | 0.39 |
| 10:18:00 PM | 16.95 | 79.96 | 0.39 |
| 11:18:00 PM | 16.30 | 80.53 | 0.36 |
| 12:18:00 AM | 15.55 | 83.53 | 0.29 |
| 1:18:00 AM | 15.05 | 86.53 | 0.23 |
| 2:18:00 AM | 14.35 | 88.86 | 0.18 |
| 3:18:00 AM | 14.10 | 90.86 | 0.15 |
| 4:18:00 AM | 13.50 | 91.86 | 0.13 |
| 5:18:00 AM | 13.20 | 93.33 | 0.10 |
| 6:18:00 AM | 15.70 | 85.43 | 0.26 |
| 7:18:00 AM | 19.65 | 69.26 | 0.70 |
| 8:18:00 AM | 25.85 | 54.90 | 1.5 |
| 9:18:00 AM | 31.80 | 39.50 | 2.84 |
| 10:18:00 AM | 34.35 | 34.23 | 3.57 |
| 11:18:00 AM | 35.25 | 33.63 | 3.78 |
| 12:18:00 PM | 37.00 | 28.80 | 4.16 |
| 1:18:00 PM | 36.00 | 32.00 | 4.23 |
| 2:18:00 PM | 32.7 | 36.13 | 3.16 |
| 3:18:00 PM | 29.10 | 40.8 | 2.39 |
| 4:18:00 PM | 26.4 | 45.93 | 1.86 |
| 5:18:00 PM | 23.25 | 54.9 | 1.29 |

## 4.2. Crop phenology

### 4.2.1. Days to emergence

There was no significant difference among the varieties on days to emergence as all plants emerged six days after planting, showing that there was good seed viability and adequate soil moisture since an equal amount of water was applied during the germination period. This result is in agreement with the finding of Beruktawit (2012) who reported that seed germination of common bean was not affected by the varieties. Similarly, Melak (2014) reported that, seed germination of chickpea was not significantly influenced by the varieties and seed rate.

### 4.2.2. Days to flowering

Days to flowering was significantly (*P*<0.01) affected by the main effect of varieties and moisture levels as well as the interaction of the two factors (Appendix Table 1). Accordingly, the earlier days to flowering (30 days) were accounted from Kufanzik variety irrespective of moisture levels, and the longer days (53 days) to flowering were recorded for Hirna variety imposed on drought stress (Table 5.). The shortest days (32 days) to flowering were taken for Ado variety compared to Hirna, Chercher, and Awash-1.

Ado and Kufanzik variety did not influenced by different soil moisture levels as they respond the same days to flowering at all treatment. However, Awash1 and Hirna variety delayed by 4 and 13 days to days flowering, respectively, as the two varieties exposed to five days of moisture stress (Table 5).

It was observed that days to flowering are different among varieties; this might be due to different genetic potential of the varieties to escape moisture stress. Previously it was reported that common bean cultivars and lines have been reported to respond differently to soil moisture deficit in terms of flowering period (Boutraa and Sanders, 2001; Molina *et al*., 2001). Similar findings were reported by Araus *et al*. (2002) who noted that flowering time is an important trait related to drought adaptation, where a short life cycle can lead to drought escape. Beruktawit *et al*. (2012) also reported that significant differences were detected among cultivars of common bean on days to flowering. Varieties treated by waterlogging stress and control moisture levels showed statistically similar results on days to flowering, but there was moderately delayed under drought stress condition; it probably due to water stress reduce cell division, thus why plants are dwarf under moisture stress condition. Escaping drought entails the completion of the life cycle in advance of the effects of drought (Heschel and Riginos, 2005; Wu *et al.*, 2010). Moisture stress can also potentially cause either plastic or evolutionary changes in avoidance or escape. Different report indicated that, with plasticity, the expression of the phenotype is shaped by environmental conditions (Via *et al.*, 1995; Schlichting and Pigliucci, 1998). A plastic response to drought would mean that the plants alter their phenotype by increasing avoidance or escape traits in drought relative to non-drought conditions (Caruso, 2006). In this study it was observed that the shortest days to flowering with Kufanzik variety compared to Hirna, Chercher, Ado and Awash-1 had stronger plasticity to escape from moisture stress through modifying the phenological stage according to the signal obtained from the environment.

### 4.2.3 Days to pod formation

The Analysis of variance showed that days to pod formation was significantly ($P$<0.01) influenced by the main effect of varieties and moisture levels as well as the interaction effect of varieties and moisture levels (Appendix Table 1).

Ado and kufanzik varieties took the shortest days to pod formation irrespective of moisture levels while; Hirna variety subjected to drought stress took the longest days to days to pod formation (Table 6.). It showed that there was an association between days to pod formation and days to flowering as earlier days to pod formation was recorded from the varieties flowered earlier. The longer days to pod formation were observed from Hirna variety subjected to drought stress; it could be due to the nature of the variety to transport most of the resource to the meristem region and enhancing flowering and early pod formation as an escaping mechanism from stress growth condition. In this respect, Hirna variety might be very slow to transport assimilate to flowering region than others. As Kudoh *et al.* (1996) reported, the individual vegetative growth is limited by the amount of total resources available for changing the size and number of vegetative and reproductive organs. Similarly, the morphological plasticity, expressed as a consequence of environmental variations, may also affects the expression of the gene that is responsible for changing the vegetative growth stage to reproductive phase (Huijser and Schmid, 2011). Such variability in maturity time might be the mechanism for plant to escape or tolerate the environmental stress condition. Moreover, sensitivity to environmental stress also varies from variety to variety. Report indicated that, the timing of phenological events and biomass allocation to different plant components can be a mechanism for the plant to adapt and such phenological plasticity may have important impacts on overall success of genotype in a particular environment(Li and Yang, 2008).

### 4.2.4 Days to physiological maturity

The main effect of varieties, moisture levels and the interaction effect of moisture levels and varieties significantly ($P<0.01$) influenced days to physiological maturity (Appendix Table 1.). It was observed that there is a variable in days to physiological maturity among varieties and moisture level; the earlier was recorded from all varieties under drought stress; Chercher under logging stress; Chercher, Kufanzik and Hirna under control treatment, but Ado and kufanzik varieties subjected to water logging were delayed by 2-6 days to reach physiological maturity as compared to others (Table 7.).

It is suggested that earliness in days to physiological maturity might be one of the mechanism for the crop to minimize the time required for vegetative growth phase and very rapidly to jump to reproductive phase before the stress causes permanent damage on plant cell. A short growing cycle has been previously recognized as a significant escape mechanism from drought in common beans (Acosta-Díaz *et al.*, 2009). In general, days to physiological maturity were earlier by 0.6 days and 2.6 days as a result of drought and waterlogging stresses compared to control (Table 7.). In the same way Rao *et al*. (2013) reported drought tolerance of early-maturing genotypes, given their lower net water requirement throughout their plant life cycle compared with late-maturing genotypes.

Days to physiological maturity was extended for Ado, Kufanzik, Awash-1 and Hirna varieties treated by logging stress, and Ado and Awash-1 varieties grown under control treatment (Table 7.). Taking longer days under water-logging stress could be due to the fact that plants exposed to water-logging stress exhibit stomata closure, limited water uptake, oxygen deficiency and substantial decline of photosynthetic rate (Ashraf and Harris, 2013). Waterlogging stress is also known to induce alterations in physiological mechanisms and cause adverse effects on several physiological and biochemical process of plants, due to the deficiency of essential nutrients like nitrogen, magnesium, potassium, and calcium (Ashraf and Harris, 2013). This is due to waterlogging stress reduced nutrient and solute transport across the plant.

Table 5. Days to flowering of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

| | **Moisture levels** | | | |
|---|---|---|---|---|
| **Varieties** | Water-logging | Control | Drought stress | **Mean** |
| Chercher | 44$^{b}$ | 42$^{c}$ | 44$^{b}$ | 43.33 |
| Ado | 32$^{g}$ | 32$^{g}$ | 32$^{g}$ | 32 |
| Kufanzik | 30$^{h}$ | 30$^{h}$ | 30$^{h}$ | 30 |
| Awash-1 | 35$^{f}$ | 35$^{f}$ | 39$^{e}$ | 36.33 |
| Hirna | 41$^{cd}$ | 40$^{de}$ | 53$^{a}$ | 46.66 |
| **Mean** | 36.4 | 35.8 | 39.6 | |
| LSD(0.05) | | 1.295 | | |
| CV (%) | | 2.08 | | |

Table 6. Days to pod formation of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

| | **Moisture levels** | | | |
|---|---|---|---|---|
| **Varieties** | Water-logging | Control | Drought stress | **Mean** |
| Chercher | 49$^{c}$ | 49$^{c}$ | 49$^{c}$ | 49 |
| Ado | 39$^{f}$ | 39$^{f}$ | 39$^{f}$ | 39 |
| Kufanzik | 39$^{f}$ | 39$^{f}$ | 39$^{f}$ | 39 |
| Awash-1 | 41$^{e}$ | 40$^{ef}$ | 55$^{b}$ | 45.33 |
| Hirna | 44$^{d}$ | 44$^{d}$ | 63a | 50.33 |
| **Mean** | 42.4 | 42.2 | 49 | |
| LSD(0.05) | | 1.69 | | |
| CV (%) | | 1.26 | | |

Table 7. Days to physiological maturity of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

| | **Moisture levels** | | | |
|---|---|---|---|---|
| **Varieties** | Water-logging | Control | Drought stress | **Mean** |
| Chercher | 85$^{bc}$ | 83$^{c}$ | 85$^{bc}$ | 84.33 |
| Ado | 89$^{a}$ | 87$^{ab}$ | 85$^{bc}$ | 87 |
| Kufanzik | 89$^{a}$ | 85$^{bc}$ | 85$^{bc}$ | 86.33 |
| Awash-1 | 87$^{ab}$ | 87$^{ab}$ | 85$^{bc}$ | 86.33 |
| Hirna | 87$^{ab}$ | 85$^{bc}$ | 84c | 85.33 |
| **Mean** | 87.4 | 85.4 | 84.8 | |
| LSD(0.05) | | 2.35 | | |
| CV (%) | | 1.63 | | |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.CV=coefficient of variance

## 4.3. Growth attributes

### 4.3.1 Leaf fresh weight and leaf dry weight

Leaf fresh weight and Leaf dry weight were significantly ($P<0.01$) influenced by the main effect of variety and moisture levels, but they were not significantly ($P>0.05$) influenced by the interaction effect of variety and moisture levels (Appendix Table1).

Among the measured varieties, the maximum leaf fresh weight was recorded from Awash-1 and Hirna variety, and the minimum leaf fresh weight was measured from Chercher, Ado and kufanzik varieties (Table 8). The highest leaf dry weight was also recorded from Awash-1 and Hirna, while the lowest leaf dry weight was measured from the Chercher, Ado and Kufanzik variety (Table 8). Regarding moisture levels, control treatment produced highest leaf fresh weight and leaf dry weight than waterlogging and drought stress treatment.

It indicated that waterlogging stress and drought stress significantly reduced leaf fresh and dry weight of common bean varieties; this could be due to low turgor pressure which suppresses cell expansion and growth leading to significant reductions in fresh and dry biomass production (Farooq *et al.*, 2009). Under the control condition, the maximum leaf fresh weight (10.92gm) and dry weight (2.10gm) producing varieties were able to give the highest grain yield. This finding agrees with the previous findings reported by Bangar *et al.* (2019)who obtained that leaf dry weight of common beans reduced when plants are exposed to drought stress. Similarly, Mohammadian *et al*. (2005) reported that leaf dry weight decreased under drought stress, as compared to non-stressed conditions. Furthermore, an early morphological response to drought stress is the avoidance mechanism through adjustment of plant growth rates such as a reduction in shoot height, basal diameter, and total fresh/ dry mass in the bean species (Lei *et al*., 2006; Kusvuran *et al*., 2011)

### 4.3.2 Leaf area and internode length

Leaf Area was significantly (P<0.01) influenced by moisture levels, but the main effect of varieties and the interaction effect did not significantly (P>0.05) influenced leaf area (Appendix Table 1).

Regarding moisture levels, the result indicated that, there is a significant difference between Control treatment and waterlogging treatment and drought stress treatment (Appendix Table 1). The maximum leaf area was measured under control growing condition and the significant reduction by 44% was recorded from waterlogging stress (Table 8.). A significant reduction by 312cm$^2$ and 218.1 cm$^2$ was observed from waterlogging and drought stress treatment compared to control (704.06cm$^2$) respectively. This finding concurs with those of Wullschleger *et al*. (2005) and Farooq *et al*. (2009), who observed that Drought stress primarily reduced leaf growth and in turn leaf area in many plant species. The senescence of leaves is commonly observed under drought conditions as a method for decreasing the leaf area from which water evaporates (Ludlow and Muchow, 1990). This can consequently lead to decreased leaf area and affect the source capacity (leaf canopy) and result in reduced photosynthetic capacity (Gwathmey and Hall, 1992). Indeed, loss of leaf area, which could be resulted from the reduced size of younger leaves and inhibition of the expansion of developing foliage, is also considered as an adaptation mechanism to moisture deficit (Acosta-Díaz *et al.*, 2009).

Internode length was significantly (*P*<0.01) influenced by varieties and moisture levels, However, the interaction effect of both factors didn’t show significantly (*P*>0.05) difference on internode length (Appendix Table 1).

The longest internode length was recorded from Awash-1 followed by Kufanzik variety. Chercher was measured in the shortest of all (Table 8). Numerically, Awash-1 and

Kufanzik varieties were similar, and they showed longer internode length when compared to others. These varieties are characterized by having climbing growth habit compared to the other varieties measured. The longest internode length was measured from the indeterminate variety and the shortest was from determinate variety, directly it revealed that the growth habit of the crop influenced the length of internode and plant height as well. This result is in agreement with the previous report of (Kelly, 2000) who stated that determinate plants also have shorter internodes and fewer nodes compared to indeterminate plants.

In the case of moisture level, the longest internode length was recorded from varieties subjected to control growing condition as compared to waterlogging stress and drought stress. The exposure of waterlogging stress and drought stress had a similar impact on internode length (Table 8).

Table 8. Growth attributes of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

| **Varieties** | **Leaf fresh weight(g)** | **Leaf dry weight(g)** | **Leaf Area ($cm^2$)** | **Internode length(cm)** |
|---|---|---|---|---|
| Chercher | $7.62^{b}$ | $1.68^{c}$ | 481.82 | $2.61^{d}$ |
| Ado | $8.81^{b}$ | $1.99^{abc}$ | 473.15 | $6.06^{c}$ |
| Kufanzik | $8.61^{b}$ | $1.81^{bc}$ | 536.67 | $9.72^{b}$ |
| Awash-1 | $11.54^{a}$ | $2.16^{a}$ | 587.67 | $12.90^{a}$ |
| Hirna | $10.92^{a}$ | $2.10^{a}$ | 557.27 | $5.92^{c}$ |
| LSD | 1.5007 | 0.3398 | 119.34 | 1.32 |
| **Moisture levels** | | | | |
| Waterlogging stress | $6.36^{c}$ | $1.42^{c}$ | $392.00^{c}$ | $6.90^{b}$ |
| Control | $12.93^{a}$ | $2.64^{a}$ | $704.06^{a}$ | $9.18^{a}$ |
| Drought stress | $9.20^{b}$ | $1.79^{b}$ | $485.89^{b}$ | $6.24^{b}$ |
| LSD (0.05%) | 1.1624 | 0.2632 | 92.437 | 1.03 |
| CV (%) | 16.36 | 18.01 | 23.44 | 18.43 |
| **Interaction** | ns | ns | ns | ns |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.CV=coefficient of variance

### 4.3.3. Leaf number, plant height and root length

The main effect of varieties and moisture levels as well as the interaction effect of varieties and moisture levels significantly (*P*< 0.01) influenced leaf number and root length of common bean varieties (Appendix Table 1).

The highest leaf number was recorded from Awash-1 variety treated by control; whereas the lowest leaf number was recorded similarly from Ado, Kufanzik and Hirna variety subjected to waterlogging and drought stress (Table 9). The leaf number was significantly reduced both under waterlogging and drought stress than control. It was observed that Cherecher, Kufanzik , Awash-1 and Hirna exposed to waterlogging throughout the growth period significantly reduced leaf number by 23.1, 14.9,38.4 and 20.3 as compared to plant exposed to control. Similarly, common bean varieties such as Cherecher ,Kufanzik , Awash-1 and Hirna exposed to water deficit for five days during the growth period were significantly reduced leaf number by 24.2, 12, 35.9 and 17.15 as compared to control, respectively. However the effect was stronger under waterlogging than deficit. In the contrary, flooding and deficit irrigation during the growth period did not significantly influenced the number of leaves developed with Ado variety.

Similar findings were reported by Boutraa *et al.* (2001) who noted that low irrigation level reduces the total number of leaves per plant.

Plant height was significantly (*P*<0.01) affected by the main effect of varieties and moisture levels as well as the interaction effect of varieties and moisture levels (Appendix Table 1). The tallest plant height was recorded from both kufanzik and Awash-1 variety treated by control and Awash-1 variety treated by logging stress, whereas the shortest plant height was measured from logging stress (Chercher and Hirna) and drought stress (Chercher, Ado and Hirna) treatment (Table 10.).

Kufanzik and Awash-1 variety showed the longest height per plant than others under control treatment. These varieties are characterized by having climbing growth habit in nature; though this increment of plant height was related their growth habit.

Under drought stress strong reduction in plant height was observed from Kufanzik and Awash-1 by 39 and 26.23 compared to control treatment. Similarly, Kufanzik and Hirna varieties exposed to water stress significantly reduced plant height by 31.78 and 16.33 as compared to control, respectively. This might be due to the reduction in plant water status which reduces shoot elongation, leaf expansion, and inhibition of cell division or cell enlargement. This finding is in line with the results of Emam *et al.* (2010) and Shenkut and Brick (2003) who reported that plant height was affected by the severe influence of water stress than unstressed. The observed reduction in plant height was associated with a decline in cell elongation and rapidly senescence of leaves in under water stress (Bhatt and Srinivasa Rao, 2005). Furthermore, Uddin *et al*., (2013) reported that plant height decreased for mungbean grown under no irrigation and it increased with the number of irrigations.

Root length was significantly ($P<0.01$) influenced by the main effect of varieties, moisture levels and the interaction effect of both varieties and moisture levels (Appendix Table 1). The mean comparison showed that the highest average root length was recorded from Kufanzik variety at control growing condition, whereas Chercher and Ado had the lowest value of average root length at waterlogging stress (Table 11).

It was due to deficiency of oxygen which affects the translocation of growth regulators and transpiration which may decrease hydraulic conductivity due to hampered root permeability during waterlogging stress.

Moreover, excess soil water level in plant root zone result in decrease in soil oxygen flux and concentration and hence oxygen level limit optimal root length and plant function(Shaw, 2015). Similar values were observed by Else et al. (2001) who obtained roots in waterlogged soils frequently die of anoxia (oxygen deficiency).

Under drought stress conditions, the longest root length goes to Chercher and Kufanzik varieties than others (Table 11.). The deeper rooting under drought stress could be mechanisms of crops respond to drought stress to contribute to greater water uptake. It was clearly stated that plants develop strategies for maintaining turgor by increasing root depth or developing an efficient root system to maximize water uptake, and by reducing water loss through reduced stomatal conductance, reduced absorption of radiation, by leaf rolling or folding and reduced leaf area (Mitra, 2001). This result is in agreement with the previous report which noted that a greater root length under water deficit conditions contributes to improved drought resistance of the common bean (White and Castillo, 1992; Polania *et al*., 2009). Under drought conditions, roots extend their length, increase their surface area, and deplete immobile nutrients (Lynch and Brown, 2012). Previous research has also shown that a deep and dense root system in common bean and high root mass (Fenta *et al*., 2011; Mohamed *et al*., 2002) correlates with effective water use under drought conditions. Also, the result indicated that lower leaf temperatures linked to higher root length as Chercher and Kufanzik variety recorded the lowest leaf temperature and higher root length under drought stress treatment. It is possibly due to varieties that deep rooter were able to maintain cooler temperatures by accessing deep water reservoirs thus maintaining water potential in adverse conditions. This finding is supported by the previous finding of Pinto *et al*. (2015), who stated that the ‘cool’ varieties under water stress, showed a deeper root system allowing the extraction of 35 % more water from the 30–90 cm soil profile.

Table 9. Effect of different soil moisture levels on leaf number of common bean varieties grown under shade house, during September 2019 to December 2019

| | **Moisture levels** | | | |
|---|---|---|---|---|
| **Varieties** | Water-logging | Control | Drought stress | **Mean** |
| Chercher | $36.22^{cd}$ | $59.33^{b}$ | $35.11^{cd}$ | 43.55 |
| Ado | $27.33^{def}$ | $35.66^{cd}$ | $28.33^{def}$ | 30.44 |
| Kufanzik | $24.22^{ef}$ | $39.11^{c}$ | $27.11^{def}$ | 30.14 |
| Awash-1 | $33.22^{cde}$ | $71.55^{a}$ | $38.66^{c}$ | 47.81 |
| Hirna | $19.33^{f}$ | $39.55^{c}$ | $22.44^{f}$ | 27.10 |
| **Mean** | 28.06 | 49.04 | 30.33 | |
| LSD(0.05) | | 9.1533 | | |
| CV (%) | | 15.28 | | |

Table 10. Effect of different soil moisture levels on plant height of common bean varieties grown under shade house, during September 2019 to December 2019

| | **Moisture levels** | | | |
|---|---|---|---|---|
| **Varieties** | Water-logging | Control | Drought stress | **Mean** |
| Chercher | $34.11^{fg}$ | $41.22^{ef}$ | $27.56^{g}$ | 34.29 |
| Ado | $44.44^{def}$ | $56.33^{cd}$ | $34.44^{fg}$ | 45.07 |
| Kufanzik | $61^{c}$ | $92.78^{a}$ | $53.78^{cde}$ | 69.18 |
| Awash-1 | $97^{a}$ | $101.67^{a}$ | $75.44^{b}$ | 91.37 |
| Hirna | $35.78^{fg}$ | $52.11^{cde}$ | $36.33^{fg}$ | 41.40 |
| **Mean** | 54.46 | 68.82 | 45.51 | |
| LSD(0.05) | | 13.19 | | |
| CV (%) | | 14.02 | | |

Table 11. Effect of different soil moisture levels on root length of common bean varieties grown under shade house, during September 2019 to December 2019

| | **Moisture levels** | | | |
|---|---|---|---|---|
| **Varieties** | Water-logging | Control | Drought stress | **Mean** |
| Chercher | $7.66^{i}$ | $31.16^{bcde}$ | $35.66^{bc}$ | 24.82 |
| Ado | $7.66^{i}$ | $31.50^{bcd}$ | $28.16^{def}$ | 22.44 |
| Kufanzik | $19.50^{gh}$ | $43.66^{a}$ | $35.16^{bc}$ | 32.77 |
| Awash-1 | $24.83^{efg}$ | $36.66^{b}$ | $29.66^{cde}$ | 30.38 |
| Hirna | $22.16^{fgh}$ | $36.66^{b}$ | $30.16^{cde}$ | 29.66 |
| **Mean** | 16.36 | 35.92 | 31.76 | |
| LSD(0.05) | | 6.3813 | | |
| CV (%) | | 13.30 | | |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.
CV=coefficient of variance

## 4.4. Physiological parameters

### 4.4.1 Leaf gas exchange parameters

#### 4.4.1.1. Transpiration and photosynthetic rates

Analysis of variance revealed that, there was a significant difference in the transpiration rate ($P<0.05$) and photosynthesis rate ($P<0.01$) due to the interaction effect of both variety and moisture levels (Appendix Table 2). The highest transpiration rate was obtained from Hirna, Kufanzik, Awash-1 and Ado variety treated by control, whereas the lowest was from recorded from all variety subjected to drought stress and Ado variety subjected to waterlogging stress (Fig.2). In overall varieties, control treatment produced the highest transpiration rate than waterlogging stress and drought stress. However, Kufanzik and Awash-1 were not affected by waterlogging stress as compared to control treatment. Perhaps, water loss from plant shoot increases the vapor pressure gradient between the ambient air and leaf and consequently increased the transpiration rate. However, a significant decline in the transpiration rate was observed from drought stress treatment. This result builds on existing evidence of Lima and Silva (2008) who obtained the physiological responses of common bean subjected to water deficit and found reductions up to 90% in the transpiration rate of non-irrigated plants compared to irrigated ones. Similarly, Silva *et al*. (2010) noted that the reduction in the transpiration rate is a response to water stress by plants. Furthermore, Hongbo *et al*. (2005) reported that with a plant species, genotypes differ in photosynthesis rate, stomatal conductance, and transpiration rate, thus, expressing different degrees of responses to water stress. Reduced photosynthesis and transpiration rates due to a decrease in the leaf water content were observed

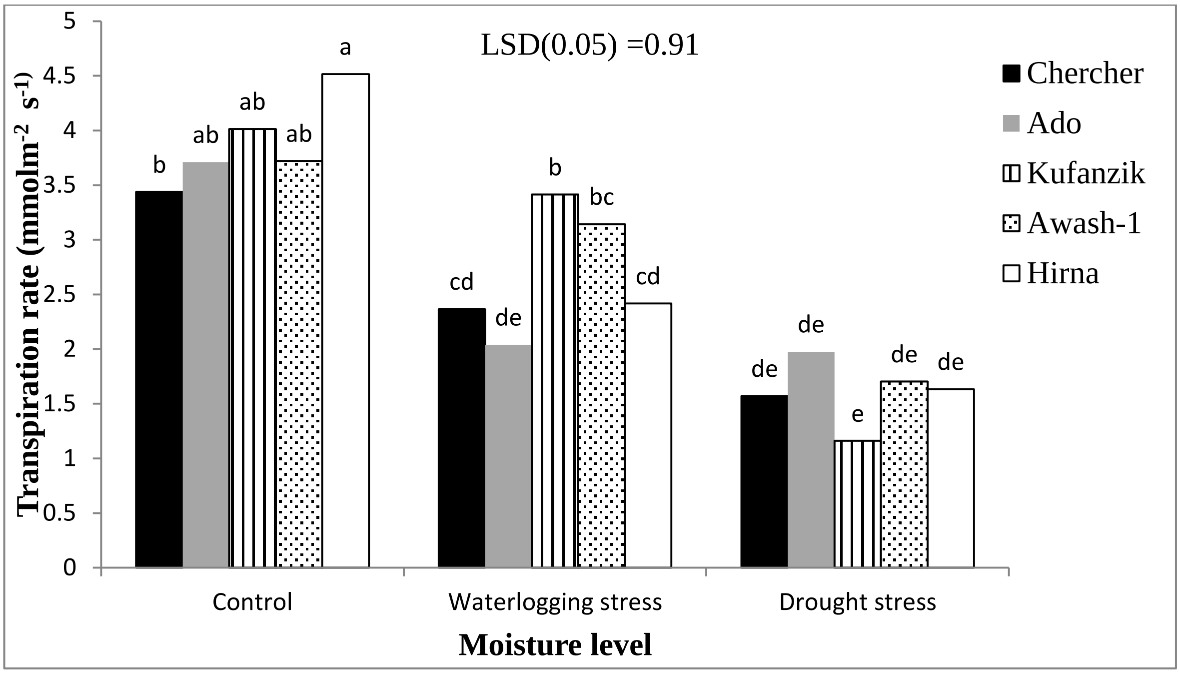

Figure 2. Mean value of transpiration rates of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

The statistical analysis of the data revealed that the photosynthetic rate was significantly (P<0.01) affected by the interaction effect of varieties and moisture levels (Appendix Table 2). Among the tested varieties Hirna variety subjected to control growing condition gave the highest photosynthesis rate, while all varieties subjected to drought stress equally accounted for the lowest photosynthesis rate (Fig.3). Under waterlogging stress, chercher (20.03) and Ado (19.45) were higher than those of Hirna (11.26), kufanzik (11.65), and Awash-1(16.36). Previously Li *et al*. (2004) found that plants exhibit certain adaptation under waterlogging stress to maintain photosynthetic capacity. Photosynthesis (CO2 assimilation) rates decreased as a result of the imposition of drought in all five varieties (Fig.3.). Photosynthesis depression at drought stress probably results from the increase in vapor pressure deficit (leaf-air) and high temperature (Breshears *et al*. 2013, *Seversike et al.* 2013) or possibly due to direct damage from water stress on the photosynthetic metabolism (Endres *et al*. 2010). Similar findings were reported by Romero *et al*. (2013) who noted that Plants grown under severe water stress reduce the photosynthesis rate substantially. In another way, significant decline of stomatal conductance under drought could hold responsible for reduced rate of photosynthesis. Under waterlogging stress; Kufanzik, Hirna, and Awash-1 varieties showed a significant decline as compared to Chercher and Ado. This might be because, plants subjected to waterlogged conditions exhibit certain alterations in physiological performance, and a prominent decrease in PSII photochemistry, which indicated the inability of the plants to regenerate rubisco under stressful conditions (Smethurst *et al*., 2005).

Besides, waterlogging stress might impair the photosynthetic electron–transport chain, and as a result limit the rate of CO2 assimilation. Moreover, Ashraf and Arfan. (2005) also reported that a decrease in transpiration and photosynthesis is attributed to stomata closure. Such reduction in photosynthesis rate might be used as a strategy to escape from stress condition. In plant photosynthetic reactions, molecular oxygen is involved as a catalyst to facilitate the assembly of energy compounds leading to the production of glucose. However, under a variety of stress conditions, plants reduce photosynthetic efficiencies, growth, and development, and yields as an avoidance strategy (Barickman *et al.*, 2019). Furthermore, factors such as reduced chlorophyll contents, leaf senescence, and reduced leaf area are also held responsible for decreased rates of photosynthetic rate under stress condition (Malik *et al*., 2001).

The damaged mesophyll cell ultrastructure of functional leaf induced by waterlogging would lead to a decline in leaf photosynthetic ability, resulting in grain yield reduction.

This finding confirms the previous study of Silva *et al.* (2010), who reported that under the high soil water level, oxygen deficiency occurs, causing stomata closure, photosystem II damage, and photosynthesis reduction.

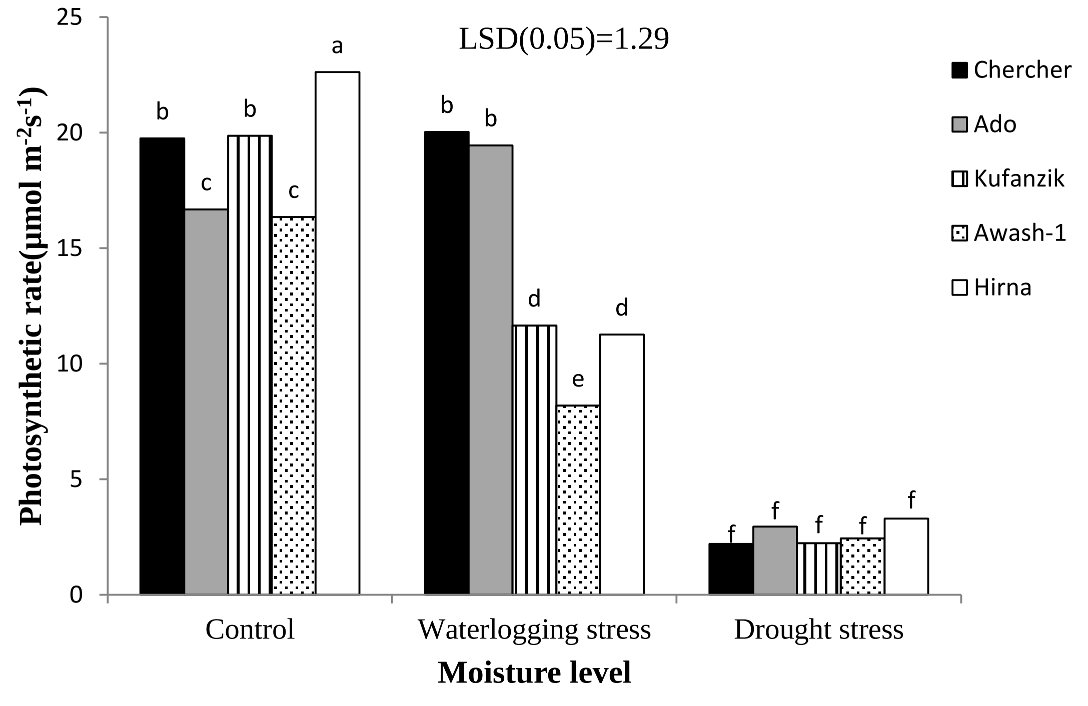

Figure 3. Mean value of photosynthesis rates of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

#### 4.4.1.2. Stomata conductance and water use efficiency

Analysis of variance result revealed that stomata conductance and water use efficiency were significantly ($P<0.01$) influenced by the main effect of varieties and moisture levels as well as the interaction effect of varieties and moisture levels (Appendix Table 2). Accordingly, Kufanzik variety treated with control moisture level recorded the highest stomatal conductance, while all varieties subjected to drought stress showed the lowest stomatal conductance (Fig. 4). In water stress conditions, root hydraulic conductivity typically decreases and results in stomata closure to reduce water loss. This could be due to the reduced amount of water in the cell which leads to turgor loss and closure of stomata (Kamara *et al*., 2003). Furthermore, lower stomatal conductance is also considered to be the mechanism of adaptation to water shortage, allowing the plant to reduce the evapotranspiration area (Beebe *et al*., 2013; Rao, 2014). Under control treatment, Ado and Awash-1 varieties significantly reduced stomatal conductance. Similarly, under waterlogging stress, significant loss of stomatal conductance was also observed from Kufanzik and Awash-1 (Fig. 4). Previous research stated that stomata conductance reactions could be due to oxygen deficiency related to ethylene production which possibly caused stomatal closure (De Martinis *et al*., 2015, Bashar *et al*., 2019).

Dutra *et al*. (2015) reported that, in response to water deficit, plants reduce stomata opening, influencing other variables such as photosynthesis rate and transpiration rate, with negative consequences on growth and development, directly affecting their yield, which justifies the reductions in the growth variables. In general, Taiz and Zeiger (2002) reported that under more severe drought conditions inhibition of cell division, inhibition of wall and protein synthesis, accumulation of solutes, the closing of stomata, and inhibition of photosynthesis were observed. The reduction in stomatal conductance was correlated with an increase in the water use efficiency, which indicates that stomatal closure contributed to optimizing water use efficiency in plants under stress, which may have enabled plants to absorb carbon by decreasing the loss of water in the water stress condition, contributing to photosynthesis maintenance (Broeckx *et al*., 2014; Roel *et al*., 2011).

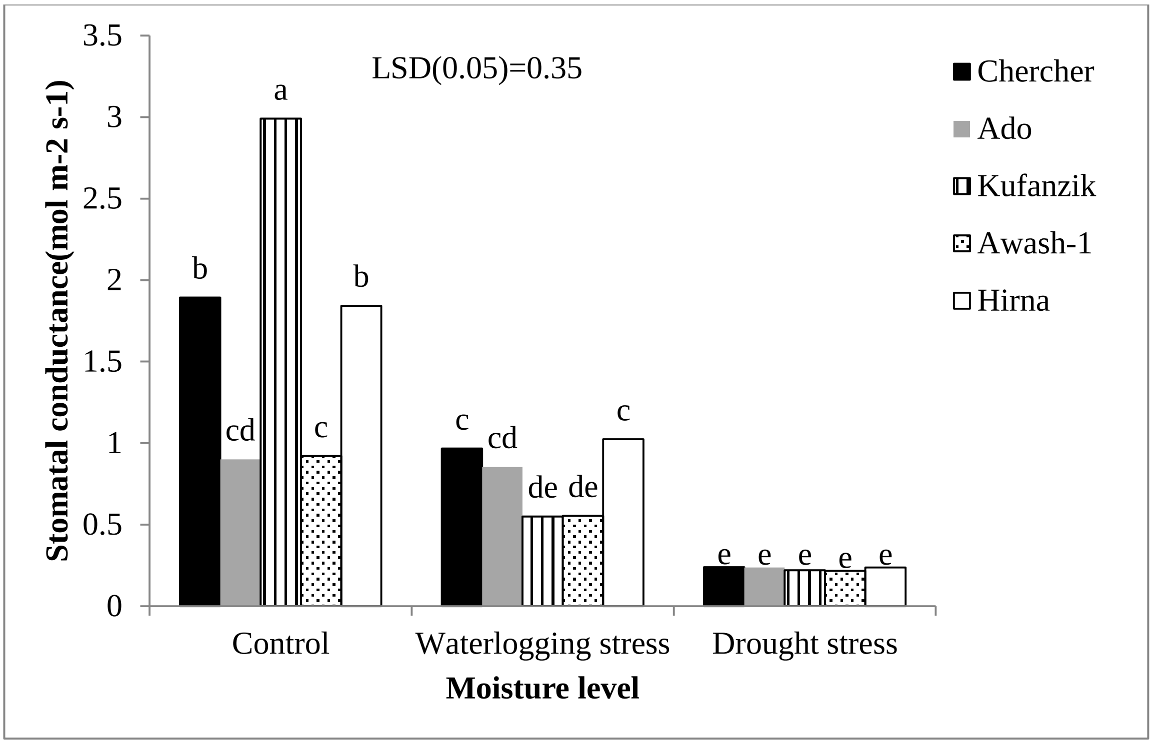

Figure 4. Mean value of stomata conductance of five common bean varieties as influenced by different soil moisture levels grown under shade house, 2019

Similarly water use efficiency was significantly influenced by the main effect of varieties and moisture levels and the interaction effect of variety and moisture level (Appendix Table 2).

The highest water use efficiency was obtained from both Ado and Chercher variety treated with logging stress, whereas the lowest water use efficiency was recorded from all varieties subjected to drought stress treatment and Awash-1 subjected to waterlogging treatment (Fig. 5). This suggests that they can produce highest dry matter under waterlogging condition through reducing amount of water loss from plant cell through transpiration. However, these results indicate that the reduction in WUE, possibly because of the down regulation of photosynthetic process while increasing water loss through stomata opening and transpiration.

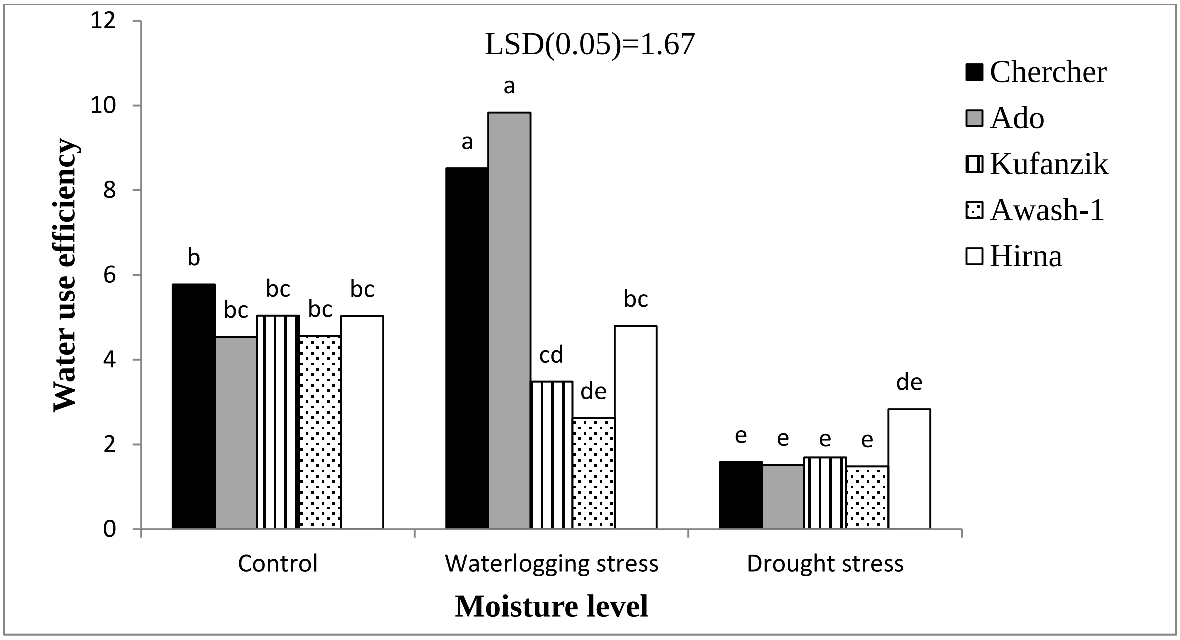

Figure 5. Mean value of water use efficiency of five common bean varieties as influenced by different soil moisture levels under shade house, 2019

### 4.4.2. Impact of moisture level on stomata anatomy

#### 4.4.2.1. Stomata number and epidermal cell number

The main effect of varieties significantly (*P*<0.001) influenced stomata variables (stomata number and epidermal cell number), but the main effect of moisture levels and interaction effect of both variety and moisture level did not show significance (*P*>0.05) difference on stomata morphology (Appendix Table 2).

The highest stomata number and epidermal cell number were recorded from kufanzik, Chercher and Awash-1 variety, whereas Hirna variety showed the lowest stomata number and epidermal cell number (Table 12). However there was no significant difference between chercher, kufanzik, and Awash-1 with respect to stomata number and epidermal cell number.

In all plants stomatal closure is regulated by the ABA (abscisic acid) hormone with both a hydropassive and a hydroactive way (Pirasteh *et al.*, 2016). According to Acosta-Díaz *et al.* (2009), stomatal closure may occur prior to alterations of the leaves' water status, which suggests the existence of early communication between the shoots and the root system, under soil dehydration.

#### 4.4.2.2. Stomata width and stomata length

Both stomata width and length were significantly (*P*<0.05) influenced by varieties, whereas moisture level and interaction effect of both did not show significance (*P*>0.05) difference on stomata width and length (Appendix Table 1).

The wider and longer stomata were observed from the Hirna variety. However, the shortest and narrowest stomata were similarly from Ado, Kufanzik, and chercher (Table 12). Reduction of stomata width and length resulting least transpiration and photosynthetic rate followed by reduced growth of the whole seedling (Belhadj *et al.*, 2011). Dutra *et al.* (2015) state that, in response to water deficit, plants reduces stomata opening. Stomata closure allows plants to limit transpiration; however, it may also limit CO2 absorption, which leads to decreased photosynthetic activity (Yang *et al*., 2006). Furthermore, the Partial closing of the stomata is a known plant tolerance strategy to water stress, because it decreases the transpiration rate, preserves leaf water content, and reduces the risk of dehydration, and eventual death by desiccation (Peak *et al*. 2004). The control of gaseous exchange between the leaf and bulk atmosphere by stomata governs $CO_2$ uptake for photosynthesis, transpiration, and a signal to modify concentration and type of the cellular osmolytes that protect cells from dehydration (Lawson and Blatt, 2014; Hu *et al.*, 2014; Krupa *et al.*, 2017). In addition to stomata closure, plants can also reduce stomata size in response to prolonged water lack and can alter their number, length, and width (Pirasteh *et al*., 2016).

In the case of moisture levels, significant differences were not observed on; Stomata number, epidermal cell number, stomata width, and length. The lack of relationship between stomatal density and drought stress showed that plants might use another mechanism for drought resistance such as stomatal conductance. In research conducted by Yadollahi *et al*. (2011), it was indicated that drought stress did not have a significant effect on length and width as well as density of the stomata in almonds (*Prunus dulcis*).

Table 12. Effect of moisture levels on stomata anatomy of common bean varieties grown under shade house during September 2019 to December 2019.

| **Varieties** | **Stomata number/mm$^2$** | **Epidermal cell number/mm$^2$** | **Stomata width(µm)** | **Stomata length(µm)** |
|---|---|---|---|---|
| Chercher | 14.44$^{ab}$ | 38.33$^{a}$ | 0.92$^{b}$ | 0.51$^{c}$ |
| Ado | 12.33$^{b}$ | 32.00$^{b}$ | 0.93$^{b}$ | 0.61$^{bc}$ |
| Kufanzik | 15.55$^{a}$ | 41.00$^{a}$ | 0.93$^{b}$ | 0.55$^{bc}$ |
| Awash-1 | 13.22$^{ab}$ | 39.11$^{a}$ | 1.04$^{b}$ | 0.63$^{b}$ |
| Hirna | 8.77$^{c}$ | 25.77c | 1.41$^{a}$ | 0.77$^{a}$ |
| Mean | 12.862 | 35.242 | 1.046 | 0.614 |
| LSD (0.05) | 2.7667 | 6.2148 | 0.1629 | 0.1054 |
| Moisture level | ns | ns | ns | ns |
| LSD (0.05%) | ns | ns | ns | ns |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.
CV=coefficient of variance

### 4.4.3. Chlorophyll content and Chlorophyll fluorescence

The result of the analysis of variance revealed that leaf chlorophyll Concentration (Chl a, Chl b, and Chl (a+b).) and Leaf chlorophyll fluorescence were significantly ($P$<0.01) affected by the interaction effect of both varieties and moisture levels (Appendix Table 2). The highest mean chlorophyll a was measured from all varieties treated with control treatment and Ado and Awash-1 exposed to drought stress, whereas the lowest mean chlorophyll-a was recorded from Ado, Kufanzik, Awash-1 and Hirna variety treated by waterlogging stress (Table 13). The reductions of chlorophyll content and photosynthetic capacity related to the disturbance of chloroplast concentration and ultrastructure of functional leaves(Niki *et al.*, 1978).This result was also in agreement with the previous study that waterlogging reduced chlorophyll content, resulting in a decline in crop leaf photosynthesis (Zhou and Lin, 1995; Pociecha, 2008), which indicated that waterlogging affected leaf chlorophyll content of common bean, and weakened the photosynthetic assimilation capacity. This might be due to decreases in soluble protein content and destruction of chloroplast membrane structure(Yordanova and Popova, 2007; Ren *et al.*, 2016). Moreover, decrease in leaf chlorophyll under waterlogging condition might be directly related to nitrogen deficiency caused by leaching and de-nitrification of the available nitrogen(Tsai *et al.*, 1992)

Under drought stress, the lowest chlorophyll-a concentration was recorded from Chercher, Kufanzik and Hirna variety; this might be interpreted as an adaptation mechanism to overcome drought stress. Similarly it was stated that, plants exposed to water deficit exhibit acclimation mechanisms, such as decreased leaf chlorophyll content (Chavez *et al.*, 2002) and increased proline production (Rosales *et al*., 2012).

Both Awash-1 and Hirna varieties treated with control moisture level accounted for the highest chlorophyll b and chlorophyll (a+b) content (Table 13), Whereas Chercher, Ado and Kufanzik variety treated with waterlogging stress accounted the lowest chlorophyll b and chlorophyll (a+b) content (Table 13.).

Similarly, Manivannan *et al*. (2007) and Saeedipour (2011) reported that chlorophyll a and b, and total chlorophyll content in sunflower and wheat plants declined in response to water stress. Similar results were reported by Singh and Raja Reddy. (2011) who stated that total chlorophylls content was reduced during drought stress in cowpea. Even though the highest chlorophyll concentration was recorded from varieties treated with the control moisture level, Chercher variety accounted for maximum chlorophyll-a and total chlorophyll concentration among varieties treated with waterlogging stress; This could be due to having unique genetic make-up which might enable the variety to cope with logging stress. Overall, leaf chlorophyll concentration was higher for all varieties subjected to control treatment, and there was significantly declined for all varieties subjected to logging stress followed by drought stress, but the reduction varies among varieties.

Mafakheri *et al*., (2010) noted that the decrease in chlorophyll under drought stress is mainly due to damage to chloroplasts caused by active oxygen species. Similar findings were reported by Chaves *et al*. (2009) and Lizana *et al*., (2006) that drought stress reduces leaf chlorophyll content.  This result disagrees with Asfaw and Blair. ( 2014)who reported that a small chlorophyll increase (4%) has been observed under drought stress.

The higher leaf chlorophyll concentration observed in the non-stressed treatment in this study was a result of the availability of moisture in the soil throughout the entire life cycle of the crop, which favors the vegetative growth and induced the plants to grow taller and produce more chlorophyll. Furthermore, the ability to maintain the leaf chlorophyll content under abiotic stress has been used as a parameter in the selection of tolerant cultivars (Kiani-Pouya and Rasouli, 2014). This result indicates that the amount of chlorophyll in the bean leaf is related to the water status of the plant, which results in high chlorophyll synthesis, consequently increasing the photosynthetic activity and promoting an increase in the yield of this activity (Pires *et al*., 2004). Reductions in leaf pigments induced by drought are considered to be an oxidative stress indicator, which might be attributed to pigment photo-oxidation, chlorophyll degradation, and/or Chlorophyll synthesis deficiency (Sánchez-Rodríguez *et al*. 2012). During water deficit, excessive generation of reactive oxygen species (ROS), such as superoxide radical (O2•–), hydrogen peroxide (H2O2), and hydroxyl radical (•OH) occurs, which causes membrane lipid peroxidation leading to irreparable metabolic and structural dysfunctions and cell death (Miller *et al*., 2010).

Results of Analysis of variance for quantum yield showed that chlorophyll fluorescence (Fv/Fm) was significantly ($P < 0.01$) influenced by the interaction effect of varieties and moisture level (Appendix Table 2.), The mean comparison of chlorophyll fluorescence indicated that, the highest Fv/Fm was observed from Chercher, Ado, Kufanzik and Hirna varieties treated by drought stress and Awas-1 subjected to control, while lowest Fv/Fm was observed from Kufanzik, Awash-1 and Hirna varieties grown under waterlogging stress and Kufanzik and Hirna variety exposed to control treatment (Table 13).

Moreover, Sairam *et al*. (2008) reported induced chlorophyll degradation and reduced photosynthesis and chlorophyll fluorescence under waterlogged conditions,.

Similarly as reported in previous study Chlorophyll fluorescence is an efficient tool for indicating changes in functions of photosynthetic apparatus, which can be damaged by waterlogging stress (Mielke *et al*., 2003; Waldhoff *et al*., 2002).

The overall result revealed that Fv/Fm showed a variation between all varieties at different moisture level, However, Strong reduction in Fv/Fm was observed in Kufanzik, Awash-1 and Hirna grown under waterlogging condition as compared to Addo and Cherecher. Findings of Santos *et al*. (2009) revealed that moderate water deficit did not promote photo-inhibition, as both drought-stressed and non-stressed plants presented Fv/Fm higher than 0.725 at the maximum water deficit.

Table 13. Chlorophyll content and chlorophyll fluorescence of five common bean varieties as affected by different soil moisture levels grown under shade house, from September 2019 to December 2019

| **Moisture level** | **Varieties** | **Chl a (µg/ml)** | **Chl b (µg/ml)** | **Total Chlorophyll** | **Chlorophyll fluorescence** |
|---|---|---|---|---|---|
| **Logging stress** | Chercher | $9.42^{abcd}$ | $5.10^{def}$ | $14.52^{cd}$ | $0.8133^{bc}$ |
| | Ado | $7.45^{g}$ | $4.74^{ef}$ | $12.20^{ef}$ | $0.8137^{bcd}$ |
| | Kufanzik | $7.25^{g}$ | $3.35^{g}$ | $10.61^{f}$ | $0.7890^{ef}$ |
| | Awash-1 | $7.56^{g}$ | $4.50^{fg}$ | $12.06^{ef}$ | $0.7867^{f}$ |
| | Hirna | $7.69^{fg}$ | $4.22^{fg}$ | $11.91^{ef}$ | $0.788^{ef}$ |
| | **Mean** | **7.87** | **4.38** | **12.26** | **0.798** |
| **Control** | Chercher | $9.70^{abc}$ | $6.85^{b}$ | $16.55^{b}$ | $0.8040^{cde}$ |
| | Ado | $9.45^{abcd}$ | $7.07^{b}$ | $16.53^{b}$ | $0.8187^{bc}$ |
| | Kufanzik | $9.82^{ab}$ | $6.60^{bc}$ | $16.43^{b}$ | $0.8007^{def}$ |
| | Awash-1 | $9.96^{ab}$ | $8.79^{a}$ | $18.75^{a}$ | $0.8217^{ab}$ |
| | Hirna | $10.33^{a}$ | $9.11^{a}$ | $19.44^{a}$ | $0.8017^{def}$ |
| | **Mean** | **9.85** | **7.68** | **17.54** | **0.80** |
| **Drought stress** | Chercher | $8.68^{cdef}$ | $5.92^{bcde}$ | $14.60^{cd}$ | $0.8357^{a}$ |
| | Ado | $9.06^{bcde}$ | $6.14^{bcd}$ | $15.21^{bc}$ | $0.8297^{ab}$ |
| | Kufanzik | $8.35^{defg}$ | $6.39^{bcd}$ | $14.75^{cd}$ | $0.8300^{ab}$ |
| | Awash-1 | $9.36^{abcd}$ | $6.17^{bcd}$ | $15.54^{bc}$ | $0.8157^{bcd}$ |
| | Hirna | $8.17^{efg}$ | $5.34^{cdef}$ | $13.52^{de}$ | $0.8247^{ab}$ |
| | **Mean** | **8.72** | **5.99** | **14.72** | **0.82** |
| | **LSD(0.05)** | 1.114 | 1.343 | 1.656 | 0.017 |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.
CV=coefficient of variance

### 4.4.4. Relative water content

Leaf relative water content was significantly (*P*<0.01) affected due to the main effect of moisture level. However, variety and the interaction effect of variety and moisture level did not significantly (*P*>0.05) influenced the relative water content of common bean varieties (Appendix Table 2).

Regarding to moisture level, control treatment produced significantly different as compared to waterlogging and drought stress. However waterlogging stress and drought stress reduced relative water content compared to control growing conditions (Table 14).

A marked reduction in the leaf water content of plants under waterlogged conditions was observed in previous studies (Kuai *et al*., 2014; Kumutha *et al*., 2008; An *et a*l., 2016). Similarly, Setter *et al*. (2009) reported that the water content decreased mainly because the root uptake capacity was restrained due to the lack of oxygen caused by waterlogging.

The highest reduction of leaf relative water content was observed from drought stress than waterlogging stress (Table 14). In a similar study, Kumar *et al*. (2006), it has been revealed that RWC in bean leaves was diminished under water deficit stress. Water deprivation leads to loss of water from the plant and changes the plant water status with a decline in the stomatal conductance and transpiration (Ribas-Carbo *et al*., 2005).

Turgor loss, decrease in leaf water potential, stomatal closure, decrease in internal CO2 concentration, all of which can lead to impairment of photosynthetic activity (Singh and Reddy, 2011). Furthermore, Reducing water loss through stomatal closure, rolling or abscission of the leaf, and increased plant water up-take through enhanced root development are mechanisms playing a role in maintaining the leaf water status (Jongdee *et al*., 2002).

### 4.4.5. Proline concentration

Proline content was significantly ($P<0.01$) affected due to the main effect of variety and moisture level. However, Interaction of moisture level × variety did not significantly ($P>0.05$) influenced proline content in leaves (Appendix Table 2).

As shown in Table 10, the proline content was significantly increased equally under drought stress and control treatment; whereas, the value of increment varied among varieties. The highest proline content belonged to Hirna, whereas the lowest proline content was equally observed from Chercher, Ado, Kufanzik, and Awash-1 (Table 14).

A relatively significant reduction was observed under waterlogging stress treatment compared to control and drought stress treatments. However, both waterlogging stress and control showed numerically similar. As an average, leaf proline content in bean plants was significantly increased by drought stress. High accumulation of proline content of Hirna variety suggests a possible high-stress tolerance mechanism as compared to Chercher, Kufanzik, Ado, and Awash-1. This value was previously interpreted as Proline accumulation may occur due to increased activity of pyroline-5-carboxylase reductase and reduced activity of proline oxidase under stress conditions (Nounjan *et al*., 2012). It has been reported that a higher proline content under water deficit conditions is useful indicators of plant tolerance, and these features can be used for the selection of tolerant genotypes (Liu *et al*., 2013; Sanchez-Reinoso *et al*., 2014). In addition, during drought stress, proline plays an important role and acts as a signaling compound to regulate mitochondria function and affect cell proliferation by means of activating particular genes, which are essential for stress recovery (Solanki and Sarangi, 2015).

Similarly in other field crops it was reported that proline content was higher after drought in Pea (Alexieva *et al*., 2001) and Chickpea (Mafakheri *et al*., 2010).

In the same orientation Vendruscolo *et al*. (2007) reported that proline accumulation in stressed plants is a tolerance mechanism against oxidative stress and it is the main strategy of plants to avoid harmful effects of drought stress. In another way, Maggio *et al*. (2002) and Zlatev and Stoyanov (2005) suggested that proline accumulation in stressed plants is not a stress tolerance mechanism, but it may be part of the stress signal influencing adaptive responses. Furthermore, the increase in the concentration of organic solutes, such as proline, sucrose, and other soluble sugars may stabilize the cellular osmotic pressure under drought stress (Sucre and Suárez, 2011)

Table 14 . Leaf relative water content and Proline content of common bean varieties grown under different soil moisture levels during September 2019 to December 2019.

| **Varieties** | **LRWC (%)** | **Proline content(µg.gm$^{-1}$FW)** |
|---|---|---|
| Chercher | 77.203 | 0.3909$^{b}$ |
| Ado | 77.573 | 0.4070$^{b}$ |
| Kufanzik | 74.182 | 0.3953$^{b}$ |
| Awash-1 | 73.211 | 0.3029$^{b}$ |
| Hirna | 78.15 | 0.6331$^{a}$ |
| **Mean** | 76.04 | 0.425 |
| **LSD(0.05)** | **ns** | **0.1427** |
| **Moisture level** | | |
| Logging stress | 75.55$^{b}$ | 0.369$^{b}$ |
| Control | 84.273$^{a}$ | 0.401$^{ab}$ |
| Drought stress | 68.368$^{c}$ | 0.506$^{a}$ |
| **Mean** | 76.06 | 0.425 |
| **LSD (0.05)** | **5.6520** | **0.1105** |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.
CV=coefficient of variance

## 4.5. Yield and yield components

### 4.5.1. Pods per plant and seeds per pod

The result of analysis of variance depicted that, pods per plant and seeds per plant were significantly ($P < 0.01$) affected by the main effect of varieties and moisture levels, However they did not significantly ($P>0.05$) influenced by the interaction effect of both variety and moisture level (Appendix Table 2). For both parameters, Chercher and Hirna varieties produced the maximum number of pods plant$^{-1}$ and seeds plant$^{-1}$, but Ado, Kufanzik, and Awash-1 similarly accounted for the minimum number of pods plant$^{-1}$ and seeds plant$^{-1}$ (Table 15). Chercher variety produced significantly higher number of pods and seeds per plant than Ado, Kufanzik and Awash-1 varieties (Table 15). This finding indicates that there is an association between pods per plant and seeds per plant as the highest number of pods per plant resulted in the maximum seeds per plant for Chercher.

With regard to moisture level, control treatment performed consistently better than logging stress and drought stress condition. The highest number of pods per plant and seeds per plant were recorded from control growing condition, and significant reduction was observed from drought stress treatment followed by waterlogging stress treatment. In line with this finding Ambachew *et al*. (2015) and Darkwa *et al*. ( 2016) reported that Drought stress affects the yield components such as number of pods per plant, number of seeds per pod, seed weight and harvest index.

### 4.5.2. Grain yield and Harvest Index

The analysis of variance revealed that significant ($P$<0.01) differences were observed among treatments in the main effects of variety and moisture level, but interaction effect did not show significance ($P$>0.05) difference on grain yield (Appendix Table 1).

The highest grain yield was recorded from the variety Hirna and kufanzik variety whereas the lowest grain yield was recorded from chercher, Ado and Awash-1 varieties (Table 15). The result showed that yield did not link to pods per plant and seeds per plant, for Hirna variety have large seed size but showed little number of pods and the greatest yield of these varieties could be due to their inherent genetic potential.

In the case of soil moisture, the effects of moisture levels on grain yield were significantly variable. The control growing condition had a positive effect on yield because control treatment gave better yield compared to logging stress and drought stress plots (Table 15). Decreasing the yield under water deficit could be a result of a reduction in the Chlorophyll content and photosynthesis efficiency as our data indicated. The reduction of grain yield under moisture stress condition may have been attributed to flower abscission and embryo abortion when drought occurred at flowering and pod filling growth stages. It was noted that post-flowering water stress caused yield losses of up to 50% due to reduced seed filling duration (Bernier *et al*., 2007; Beebe *et al*., 2013). Moreover, water stress during the flowering and pod filling periods reduced seed yield and seed weight and accelerated the maturity of dry bean (Szilagyi, 2003).

Drought stress condition causes a significant reduction on grain yield and biological yield of common bean (Tar'an and Singh, 2002). In crops such as the common bean, in which the product of interest is the grain, the main criterion for the selection of cultivars tolerant to low water availability is related to the characteristics that result in high grain production (Rosales *et al*., 2012)

Table 15. Mean value of yield and yield components of five common bean varieties as influenced by different soil moisture level under shade house, September 2019 to December 2019

| **Varieties** | **Pods per plant** | **Seeds per plant** | **Grain yield per plant (g)** |
|---|---|---|---|
| Chercher | $4.66^{a}$ | $15.21^{a}$ | $3.98^{c}$ |
| Ado | $3.42^{b}$ | $11.80^{b}$ | $4.14^{c}$ |
| Kufanzik | $3.32^{b}$ | $10.27^{b}$ | $5.25^{ab}$ |
| Awash-1 | $3.53^{b}$ | $10.50^{b}$ | $4.43^{bc}$ |
| Hirna | $4.19^{ab}$ | $12.99^{ab}$ | $5.45^{a}$ |
| **Mean** | 3.824 | 12.154 | 4.65 |
| LSD(0.05) | 0.95 | 3.06 | 0.96 |
| **Moisture level** | | | |
| Logging stress | $3.34^{b}$ | $10.28^{b}$ | $4.43^{b}$ |
| Control | $5.66^{a}$ | $19.22^{a}$ | $7.44^{a}$ |
| Drought stress | $2.47^{c}$ | $6.96^{c}$ | $2.09^{c}$ |
| **Mean** | 3.82 | 12.15 | 4.65 |
| LSD (0.05) | 0.74 | 2.37 | 0.75 |
| CV (%) | 25.85 | 26.08 | 21.53 |

Means sharing the same letter in a column of treatment are not statistically significant at the 95% confidence level based on the LSD (Least significance difference) comparison method.
CV=coefficient of variance

The harvest index was significantly influenced by moisture level (*P*<0.01) and the interaction effect of variety and moisture level (*P*<0.05). However there was a non-significant difference among varieties (*P*>0.05) (Appendix Table 2).

Accordingly, Hirna, kufanzik, Chercher and Awash-1 varieties grown under control treatment and Kufanzik variety subjected to waterlogging stress treatment produced the highest harvest index; whereas kufanzik variety treated with drought stress gave the lowest of all (Fig. 6). The increment of harvest index for Chercher and Hirna variety was due to having the highest grain yield with the lowest biological yield. The highest reduction was relatively recorded from drought stress treatment followed by waterlogging stress.

This result is in line with the previous findings which noted that drought stress affects the yield components such as the number of pods per plant, a number of seeds per pod, seed weight, and harvest index (Ambachew *et al*., 2015; Darkwa *et al*., 2016). Furthermore, Reduction in harvest index was observed as a result of moderate moisture stress in common beans (Kellman, 2008). Thus, traits of possible interest for improving crop tolerance to drought would include a high harvest index (Turner *et al*., 2003; Richards, 2006).

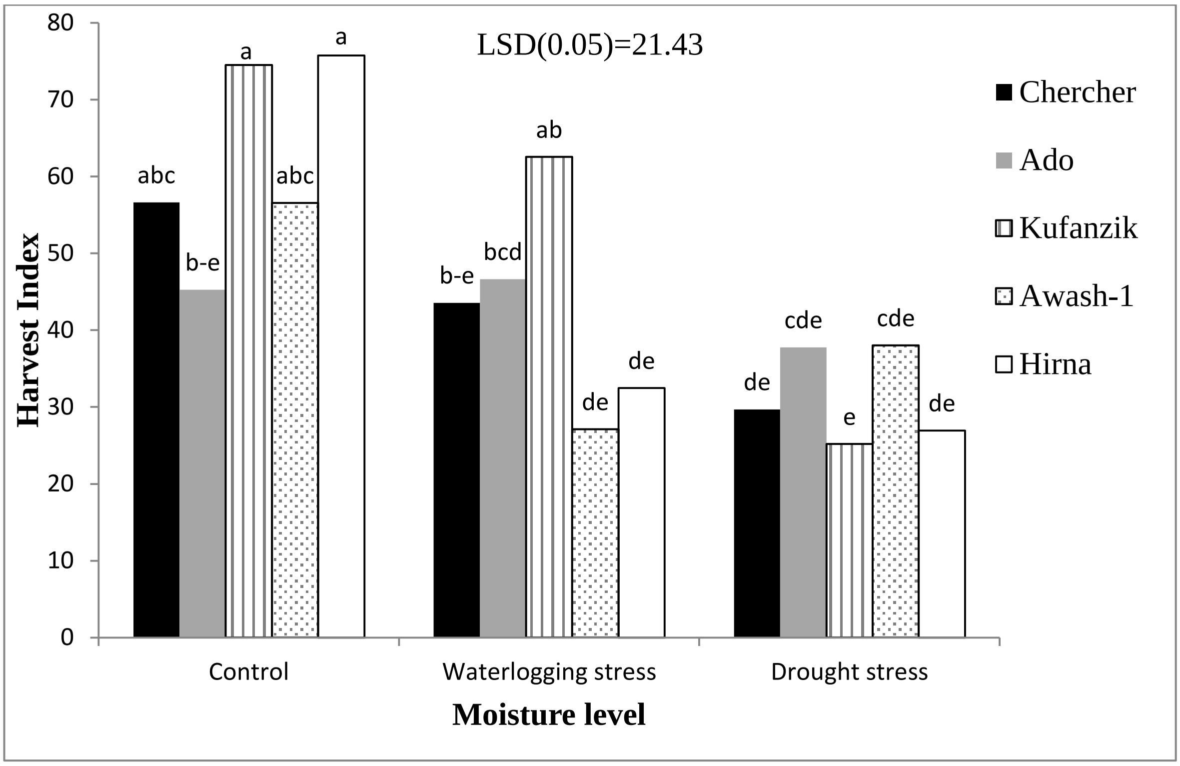

Figure 6. Mean value of Harvest index of five common bean varieties as influenced by different soil moisture levels grown under shade house, 2019

## 4.6. Correlation Analysis

### 4.6.1. Correlation result of morphological, physiological and yield components of common bean varieties exposed to different soil moisture level

The correlation values explained the association between different analyzed parameters and clearly indicated the magnitude of their relationships.

Correlation analysis indicated that, all morphological traits had significant (*P*<0.001) and positive correlation with stomata anatomy (Table 16). Leaf area showed a positive and strong correlation with leaf fresh weight (r=0.97) and leaf dry weight(r=0.96) (Table 16). There was also a correlation between plant height and internode length (r=0.97) as the tallest plant height was measured from the highest internode length variety (Table 16).

Relative water content was highly correlated to stomata number(r=0.95), stomata length (r=0.97), and stomata width (r=0.96) and root length (r=0.94) (Table 18) .Previous research has also shown that a deep and dense root system in common bean and high root mass (Fenta *et al*., 2011; Mohamed *et al*., 2002) correlates with effective water use under drought conditions. It is possibly due to varieties that deep rooter were able to maintain cooler temperatures by accessing deep water reservoirs thus maintaining water potential in adverse conditions. Moreover, Sponchiado *et al*. (1989) demonstrated that deep rooting has been positively correlated with seed yield, crop growth, cooler canopy temperature, and soil water extraction in common beans.

The correlation result also demonstrates a correlation between physiological traits and yield components

There was observed that a positive and high magnitude correlation of photosynthetic rate with water use efficiency(r=0.94), grain yield (r=0.95) and harvest index(r=0.91). Transpiration rate also positively and significantly correlated with grain yield(r=0.95) and harvest index(r=0.94) (Table 17), indicating that a significant decrease in grain yield and yield components were associated with a significant decrease in transpiration rate and photosynthetic rate. Similarly, Malik *et al*. (2001) reported that reduced photosynthetic rate held responsible for decreased grain yield and yield components.

It was also observed that proline content was significantly and positively correlated with relative water content (r=0.91), similarly, Farooq *et al*. (2009) indicated that there was a strong correlation between plant water content and accumulation of compatible solutes (proline) under drought stress.

In general, these correlations suggest that a rapid accumulation of canopy biomasss through an effective use of water, combined with an efficient remobilization of reserves to pod and grain formation is an important adaptive strategy to water deficit.

Table 16. Pearson Correlation coefficient(r) among morphological traits and stomata anatomy of common bean varieties grown under different soil moisture levels from September 2019 to December 2019

| | **SN** | **SL** | **SW** | **LFW** | **LDW** | **LN** | **PH** | **LA** | **IL** | **RL** |
|---|---|---|---|---|---|---|---|---|---|---|
| **SN** | | | | | | | | | | |
| **SL** | 0.91 | | | | | | | | | |
| **SW** | 0.90 | 0.98 | | | | | | | | |
| **LFW** | 0.87 | 0.93 | 0.94 | | | | | | | |
| **LDW** | 0.89 | 0.93 | 0.93 | 0.98 | | | | | | |
| **LN** | 0.91 | 0.89 | 0.89 | 0.93 | 0.94 | | | | | |
| **PH** | 0.90 | 0.88 | 0.88 | 0.91 | 0.91 | 0.91 | | | | |
| **LA** | 0.90 | 0.93 | 0.93 | 0.97 | 0.96 | 0.94 | 0.91 | | | |
| **IL** | 0.85 | 0.86 | 0.86 | 0.89 | 0.88 | 0.86 | 0.97 | 0.89 | | |
| **RL** | 0.91 | 0.94 | 0.94 | 0.96 | 0.95 | 0.92 | 0.91 | 0.96 | 0.89 | |
| **PC** | 0.85 | 0.92 | 0.93 | 0.87 | 0.87 | 0.80 | 0.77 | 0.86 | 0.75 | 0.87 |

Where, SN=Stomata number, SL=Stomata length, SW=Stomata width, LFW= Leaf fresh weight, LDW=Leaf dry weight, LN=Leaf number, PH=Plant height, LA=Leaf area, IL=Internode length, RL=Root length, PC=Proline content, all values were significantly and positively correlated at (p≤0.001)

Table 17. Pearson Correlation coefficient(r) among physiological traits and yield components of common bean varieties grown under different soil moisture levels from September 2019 to December 2019

| | **Chl-a** | **Chl-b** | **Chl (a+b)** | **RWC** | **Gs** | **Pn** | **E** | **Wue** | **GY** | **HI** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Chl-a** | | | | | | | | | | |
| **Chl-b** | 0.98 | | | | | | | | | |
| **Chl (a+b)** | 0.99 | 0.99 | | | | | | | | |
| **RWC** | 0.99 | 0.96 | 0.99 | | | | | | | |
| **Gs** | 0.79 | 0.78 | 0.70 | 0.78 | | | | | | |
| **Pn** | 0.86 | 0.85 | 0.86 | 0.87 | 0.90 | | | | | |
| **E** | 0.94 | 0.93 | 0.94 | 0.94 | 0.86 | 0.92 | | | | |
| **Wue** | 0.85 | 0.81 | 0.84 | 0.87 | 0.79 | 0.94 | 0.82 | | | |
| **GY** | 0.93 | 0.90 | 0.90 | 0.89 | 0.89 | 0.95 | 0.95 | 0.85 | | |
| **HI** | 0.93 | 0.91 | 0.93 | 0.92 | 0.86 | 0.91 | 0.94 | 0.86 | 0.96 | - |

Where, Chl-a= Chlorophyll-a, Ch-b=Chlorophyll-b, Chl (a+b) =Chlorophyll (a+b), RWC=Relative water content, Gs=Stomata conductance, Pn=Photosynthetic rate, E=Transpiration rate, Wue=Water use efficiency, GY=Grain yield, HI=Harvest index, all values were significantly and positively correlated at (p≤0.001)

Table 18. Pearson Correlation coefficient(r) among morphological traits, physiological traits and yield components of common bean varieties grown under different soil moisture levels from September 2019 to December 2019

| | | | | | LD | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **SN** | **SL** | **SW** | **LFW** | **W** | **LN** | **PH** | **LA** | **IL** | **RL** | **PC** |
| **Chl-a** | 0.95 | 0.96 | 0.96 | 0.95 | 0.96 | 0.94 | 0.91 | 0.95 | 0.88 | 0.95 | 0.91 |
| **Chl-b** | 0.91 | 0.94 | 0.94 | 0.96 | 0.96 | 0.95 | 0.90 | 0.96 | 0.88 | 0.96 | 0.88 |
| **Chl(a+b)** | 0.94 | 0.96 | 0.96 | 0.966 | 0.97 | 0.95 | 0.91 | 0.96 | 0.88 | 0.96 | 0.90 |
| **Fv/Fm** | 0.96 | 0.97 | 0.93 | 0.94 | 0.94 | 0.93 | 0.91 | 0.94 | 0.87 | 0.95 | 0.92 |
| **RWC** | 0.95 | 0.97 | 0.96 | 0.94 | 0.94 | 0.93 | 0.91 | 0.94 | 0.87 | 0.94 | 0.91 |
| **SC** | 0.70 | 0.73 | 0.75 | 0.78 | 0.79 | 0.78 | 0.75 | 0.80 | 0.72 | 0.78 | 0.64 |
| **Pn** | 0.79 | 0.80 | 0.81 | 0.82 | 0.85 | 0.86 | 0.80 | 0.84 | 0.76 | 0.78 | 0.72 |
| **E** | 0.89 | 0.90 | 0.91 | 0.93 | 0.94 | 0.92 | 0.91 | 0.93 | 0.88 | 0.91 | 0.81 |
| **Wue** | 0.81 | 0.82 | 0.81 | 0.76 | 0.80 | 0.81 | 0.75 | 0.79 | 0.71 | 0.73 | 0.76 |
| **SPP** | 0.84 | 0.85 | 0.85 | 0.90 | 0.92 | 0.91 | 0.82 | 0.91 | 0.79 | 0.87 | 0.77 |
| **PPP** | 0.87 | 0.88 | 0.89 | 0.92 | 0.93 | 0.93 | 0.85 | 0.92 | 0.81 | 0.89 | 0.81 |
| **GY** | 0.83 | 0.85 | 0.85 | 0.90 | 0.90 | 0.89 | 0.87 | 0.90 | 0.85 | 0.86 | 0.77 |
| **HI** | 0.89 | 0.88 | 0.88 | 0.90 | 0.91 | 0.90 | 0.87 | 0.91 | 0.84 | 0.88 | 0.81 |

Where, SN=Stomata number, SL=Stomata length, SW=Stomata width, LFW= Leaf fresh weight, LDW=Leaf dry weight, LN=Leaf number, PH=Plant height, LA=Leaf area, IL=Internode length, RL=Root length, PC=Proline content, Chl-a=Chlorophyll-a, Chl-b=Chlorophyll-b, Chl(a+b)=Chlorophyll (a+b), Fv/Fm=Chlorophyll fluorescence, RWC=Relative water content, SC=Stomata conductance, Pn=Photosynthetic rate, E=Transpiration rate, Wue=Water use efficiency, SPP=Seeds per plant, PPP=Pods per plant, GY=Grain yield, HI=Harvest index; all values were significantly and positively correlated at ($p \leq 0.001$)

# 5. SUMMARY AND CONCLUSION

Common bean is an herbaceous annual plant grown worldwide for its edible dry seeds or green unripe pods. Common bean is a highly polymorphic warm-season crop that has two growth habits (herbaceous bushes (determinate) and climbing vines (indeterminate).Bean is particularly suitable for food security due to its short growing cycle and adaptability to different cropping systems.

In Ethiopia, common bean is mainly grown in Eastern, Southern, Southwestern, and Rift valley areas of the country, and it is one of the fast-expanding legumes crops that provide an essential part of the daily diet and foreign earnings.

Drought and waterlogging stresses are among rapidly increasing constraints to agricultural production particularly for short-season grain legume crops such as a common bean. Drought and waterlogging treatments reduced common bean yield regardless of varieties, however, drought stress affected grain yield more severely than waterlogging stress. Plants have diverse mechanisms for response and adaptation to water stress; therefore, the determination of their distinct morphological, physiological, and agronomic traits for drought tolerance is indispensable to ensure efficiency in the selection process. Development of common bean varieties that are adapted to different scenarios of drought conditions can help to increase the available knowledge regarding the behavior of common bean varieties to moisture stress

The experiment was conducted under shade house from September 2019 to December 2019, at Hawassa University College of Agriculture. The treatment was comprised of a factorial combination of five common bean Varieties (Hirna, kufanzik, Awash-1, Ado, and Chercher) and three moisture levels (control, waterlogging stress, and drought stress) with three replication, totally 15 treatment combination was formed.

The results of this study showed that days to physiological maturity were fastened equally, as crops treated by control and drought stress, but both days to flowering and days to pod formation were not influenced by moisture level. Growth parameters such as leaf number and root length, and plant height of the crops were increased from control treatment compared to waterlogging stress and drought stress, whereas leaf fresh weight, leaf dry weight, leaf area, internode length, stomata number, epidermal cell number, stomata width, and stomata length and relative water content did not show a significant difference in interaction effect of varieties and moisture levels, but significantly influenced by variety and moisture levels.

Physiological parameters such as photosynthetic rate, transpiration rate, stomata conductance, water use efficiency, chlorophyll-a, chlorophyll-b, chlorophyll (a+b), chlorophyll fluorescence (Fv/Fm) were significantly influenced by the interaction effect of variety and moisture level.

Yield parameters such as pods per plant, seeds per plant and grain yield per plant were significantly influenced by varieties as well as moisture level, but they did not affect due to the interaction effect of varieties and moisture levels, However, maximum seed yield per plant was obtained from Hirna and kufanzik varieties, whereas harvest index of yield parameter showed a significant difference in the interaction effect of variety and moisture level.

In general, among tested varieties, Hirna and Kufanzik Varieties were considered as tolerant as they were able to maintain their phenotypic plasticity and performed better yield compared to Chercher, Awash-1 and Ado, but Chercher variety was able to tolerate under water-logging stress than others. Varieties exposed to drought stress and waterlogging significantly reduced all tested parameters, except for crop phenology and proline concentration as compared to daily watering (control) treatment

Correlation analysis indicates that all growth parameters were significantly correlated with physiological variables, seed yield. More interestingly, grain yield was significantly and positively correlated with the Transpiration rate, photosynthetic rate, and water use efficiency as expected it was meant to be, this revealed that the carbon assimilation rate had a great role in dry mass production.

**In conclusion**, this finding suggests that waterlogging stress and drought stress does have a detrimental effect on the morphological, physiological and yield components of common bean. The reduction of photosynthesis induced by drought stress and waterlogging are a consequence of chlorophyll content and relative water content reduction, resulting in a significant reduction in grain yield of common bean.

From this study Hirna and Kufanzik Varieties were considered as tolerant as they were able to maintain their phenotypic plasticity and performed better yield compared to Chercher, Awash-1 and Ado, but Chercher variety was able to tolerate under logging stress than others.

This study also showed that accumulation of proline content was equally increased under control and drought stress treatment

The simplest assessment of tolerance in response to water stress is the capacity of a plant to grow and remain alive under progressively increasing water deficit or waterlogging conditions. The results also suggest that varieties with determinate growth habit might have the potential to survive to waterlog stress and drought stress than indeterminate climbing varieties.

It is possible to interpret that traits associated with drought tolerance might be due to having unique genetic variability and they could be a most promising to maintain phenotypic plasticity under waterlogging and drought stress.

**Overall it was possible to put away that,** this finding revealed common bean varieties respond differently to the various moisture level suggesting that the possibility of selecting varieties that have the potential to cope with water stress.

From this study Hirna and Kufanzik Varieties were considered as tolerant as they were able to maintain their phenotypic plasticity and performed better yield compared to Chercher, Awash-1 and Ado, but Chercher variety was able to tolerate under logging stress than others. It must be noted in mind that this study was only conducted on a specific common bean variety in one season. Further research is hence needed under field condition to determine the moisture stress effects on a large number of common bean varieties before a generalized conclusion can be drawn.

## 6. REFERENCES

Abebe, H., Setegn, G., Habtamu, Z. (2013.). Differential effects of post-flowering drought stress on growth and yield of the basic generations of two common bean (Phaseolus vulgaris L.) populations. Star J., 2(1), 22-31.

Abedi T., Pakniyat H. (2010). Antioxidant enzyme changes in response to drought stress in ten cultivars of oilseed rape (Brassica napus L.). –Czech. J. Genet. Plant 46: 27-34.

Acosta-Díaz, E., Acosta-Gallegos, J., Trejo-López, C., Padilla-Ramírez, J. & Amador-Ramírez, M. (2009). Adaptation traits in dry bean cultivars grown under drought stress. *Agricultura técnica en México* 35(4): 419-428.

Agbicodo, E., Fatokun, C., Muranaka, S., Visser, R. (2009).Breeding drought tolerant cowpea: Constraints, accomplishments, and future prospects. Euphytica, 167, 353–370.

Ahmed, F., Suliman, A. (2010). Effect of water stress applied at dierent stages of growth on seed yield and water-use efficiency of Cowpea. Agric. Biol. J. North Am., 1, 534–540.

Akibode,S. (2011). Trends in the Production, trade, and consumption of food-legume crops in sub-saharan africa. MSc Hesis Michigan State University.

Alemu, D. and A.Bekele .(2005). Evaluating the marketing opportunity for the Ethiopian beans. Unpublished report

Alexieva ,V., Sergiev, I., Mapelli, S., Karanov, E .(2001). The effect of drought and ultraviolet radiation on growth and stress markers in pea and wheat. Plant Cell Environ 24: 1337–1344.

Ambachew, D., Mekbib, F., Asfaw, A., et al. (2015). Trait associations in common bean genotypes grown under drought stress and field infestation by BSM bean fly. The Crop J 3: 305–316.

Anjum, F., Yaseen, M., Rasul, E., Wahid, A., & Anjum, S. (2003). Water stress in barley (Hordeum vulgare L.). II. Effect on chemical composition and chlorophyll contents; Pak. J. Agric. Sci, 40, 45-49. photosynthesis.

Araus,J,. Slafer,M., Reynolds,and C.Royo.(2002).Plant breeding and drought in C3 cereals:What should we breed for? Ann.Bot.89(SPECK.ISS.):925-940

Asfaw, M.W. Blair, (2014). Quantification of drought tolerance in Ethiopian common bean varieties, Agric. Sci. 5:124–139

Ashraf,M., Arfan, M .(2005). Gas exchange characteristics and water relations in two cultivars of Hibiscus esculentus under waterlogging. Biol. Plant, 49: 459-462.

Ashraf, M. & Harris, P. J. (2013). Photosynthesis under stressful environments: an overview. *Photosynthetica* 51(2): 163-190.

Assefa, T., Abebe, G., Fininsa, C., Tesso, B. & Al-Tawaha, A.-R. M. (2005). Participatory bean breeding with women and small holder farmers in eastern Ethiopia. *World Journal of Agricultural Sciences* 1(1): 28-35.

Atkinson, N. J., and Urwin, P. E. (2012). The interaction of plant biotic and abiotic stresses: from genes to the field. J. Exp. Bot. 63, 3523–3543.

Ayra, L., Ramírez, M., Íñiguez, L. P., Rodés, R., Ortega, E. & Hernández, G. (2018). The common bean (Phaseolus vulgaris) Basic Leucine Zipper (bZIP) transcription factor family: response to salinity stress in fertilized and symbiotic N2-fixing plants. *Agriculture* 8(10): 160.

Bala Subramanian V., Maheswari M. (1992). Compensatory growth responses during reproductive phase of cowpea after relief of water stress. Journal of Agronomy and Crop Science 168:85-90.

Bangar, P., Chaudhury, A., Tiwari, B., Kumar, S., Kumari, R., Bhat, K.V. (2019).Morphophysiological and biochemicalresponse of mungbean (vigna radiata L.) varieties at different developmental stages under drought stress.Turkish J. Biol., 43, 58–69.

Barickman, T. C., Simpson, C. R. & Sams, C. E. (2019). Waterlogging causes early modification in the physiological performance, carotenoids, chlorophylls, proline, and soluble sugars of cucumber plants. *Plants* 8(6): 160.

Bashar, K., Tareq, M., Amin, M., Honi, U., tahjib-Ul-Arif, M., Sadat, M., Hossen, Q.M.M. (2019). Phytohormone-Mediated Stomatal Response, Escape and Quiescence Strategies in Plants under FloodingStress. Agronomy, 9, 43.

Bastos, F., Soares, F., Sousa, C., Tavares, C., Teixeira, M., & Sousa,C. (2016). Common bean yield under water suppression and application of osmoprotectants. Revista Brasileira de Engenharia Agrícola e Ambiental, 20(8), 697-701. https://doi.org/10.1590/18071929/agriambi.v20n8p697-701

Becana, M., Moran, J. & Iturbe-Ormaetxe, I. (1998). Iron-dependent oxygen free radical generation in plants subjected to environmental stress: toxicity and antioxidant protection. *Plant and soil* 201(1): 137-147.

Beebe, S., Rao, I., Cajiao, C., Grajales, M . (2008). Selection for drought resistance in common bean also improves yield in ph osphorus limited and favorable environments. Crop Science 48:582-592 .

Beebe, S., Rao, I., Blair, M. & Acosta, J. (2013). Phenotyping common beans for adaptation to drought. *Frontiers in physiology* 4: 35.

Belhadj, S., A. Derridj, A. Moriana, C Gijon., P. Mevy and T. Gauquelin. (2011). Comparative analysis of stomatal characters in eight wild atlas pistachio populations (Pistacia atlantica Desf.; Anacardiaceae). Int. Res. J. Plant Sci., 2(3): 060-069.

Bernier, J., Kumar, A., Ramaiah, V.,Spaner, D., Atlin, G., (2007). A large-effect QTL for grain yield under reproductivestage drought stress in uplandrice. Crop Sci., 47, 507-518.

Bertolde, F., Almeida, A., Pirovani, P., et al.: (2012).Physiological and biochemical responses of Theobroma cacao L. genotypes to flooding. – Photosynthetica 50: 447-457.

Beruktawit, M., Tamada, T., Nigussie, D . (2012). Response of common bean (Phaseolus Vulgaris L.) cultivars with different growth habits to plant density at Haramaya, Eastern Ethiopia. 29 p.

Beshir, H., Walley, F., Bueckert, R. & Tar'an, B. (2015). Response of snap bean cultivars to Rhizobium inoculation under dryland agriculture in Ethiopia. *Agronomy* 5(3): 291-308.

Bhatt, R., Srinivasa Rao NK .(2005). Influence of pod load response of okra to water stress. Ind J Plant Physiol 10: 54-59.

Bisbis, M., Gruda, N., & Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality—A review. J. Clean. Prod, 170, 1602-1620. https://doi.org/10.1016/j.jclepro.2017.09.224

Bougrier, S., Geairon, P., Deslous-Paoli, J., Bacher, C. & Jonquières, G. (1995). Allometric relationships and effects of temperature on clearance and oxygen consumption rates of Crassostrea gigas (Thunberg). *Aquaculture* 134(1-2): 143-154.

Boutraa, T. & Sanders, F. (2001). Influence of water stress on grain yield and vegetative growth of two cultivars of bean (Phaseolus vulgaris L.). *Journal of Agronomy and Crop Science* 187(4): 251-257.

Bray, E., Bailey-Serres, J., & Weretilnyk, E. (2000). Responses to abiotic stresses. In W. Gruissem, B. Buchannan, & R. Jones (Eds.), Biochemistry and Molecular Biology of Plants(pp. 1158-1249). ASPP: Rockville, MD, USA.

Breshears, D., Adams, H., Eamus, D., Mcdowell, N., law, D., will, R., Williams, P. and zou CB. (2013). The critical amplifying role of increasing atmospheric moisture demand on tree mortality and associated regional die off opinion article. Front plant sci 4: 266.

Broeckx, L., Fichot, R., Verlinden, M. and Ceulemans R. (2014). Seasonal variations in photosynthesis, intrinsic water-use efficiency and stable isotope composition of poplar leaves in a short-rotation plantation. Tree Physiol 34: 1-14.

Broughton, W. J., Hernandez, G., Blair, M., Beebe, S., Gepts, P. & Vanderleyden, J. (2003). Beans (Phaseolus spp.)–model food legumes. *Plant and soil* 252(1): 55-128.

Brunner, I., Herzog, C., Dawes, M. A., Arend, M., and Sperisen, C. (2015). How treeroots respond to drought. Front. Plant Sci. 6:547. doi: 10.3389/fpls.2015.00547

Buruchara, R .(2007). Background information on common beans (Phaseolus vulgaris L) in biotechnology, breeding & seed systems for African crops

Calvache, M., Reichardt, K., Bacchp, O. S., & Dourado-Neto, D. (1997). Deficit irrigation at different growth stages of the common bean (Phaseolus vulgarisL.). Scientia Agricola Piracicaba, 54, 1–16.

Caruso, C. M. (2006). Plasticity of inflorescence traits in Lobelia siphilitica (Lobeliaceae) in response to soil water availability. *American journal of botany* 93(4): 531-538.

Carvalho, J. J., Saad, J. C. C., Cunha,F. N., Silva, N. F., & Teixeira, M.B. (2014). Manejo da irrigação no feijoeiro, cultivado em semeadura direta e convencional. Revista Brasileira de Agricultura Irrigada, 8, 52-63. https://doi.org/10.7127/rbai.v8n100198

Celik, G. and E. Turhan. (2011). Genotypic variation in growth and physiological responses ofcommon bean (Phaseolus vulgarisL.) seedlings to flooding. Afr. J. Biotechnol. 10:7372–7380

Central Statistics Authority (CSA). (2011). Agricultural Sample Survey 2010/11. Report on Area and Production of Crops (Privat3 Peasant Holdings, “Meher” Season), Vol. IV Statistical Bulletin 446, Addis Ababa: May, 2011. 1-82

Chaves MM, Pereira JS, Maroco J, Rodrigues ML, Ricardo CPP, Osorio ML, Carvalho I, Faria T, Pinheiro C (2002). How plants cope with water stress in the field? Photosynthesis and growt h. Annals of Botany 89:907-916

Chekanai, V., Chikowo, R. & Vanlauwe, B. (2018). Response of common bean (Phaseolus vulgaris L.) to nitrogen, phosphorus and rhizobia inoculation across variable soils in Zimbabwe. *Agriculture, ecosystems & environment* 266: 167-173.

CIAT (International Center for Tropical Agriculture). (2008). Highlights CIAT in Africa. New bean varieties for ethiopian farmers. Africa coordination kawanda agricultural research institute Kampala, Uganda.

Costa-Franca MG, Pham-Thi AT, Pimentel C, Pereyra-Rossiello RO, Zuily- Fodil Y, Laffray D .(2000). Differences in growth an d water relations among Phaseolus vulgaris cultivars in response to induced drought stress. Environmental and Experimental Bota ny 43:227-237.

Crawford, R.M.M., (2003). Seasonal differences inplant responses toflooding and anoxia. Can. J. Bot., 81: 1224-1246.

CSA (Central Statistics Agency of Ethiopia) (2016) Report on area and crop production of major crops for Meher season, 1: 125.

Dagnew, K., Haileselassie, T., & Feyissa, T. (2014). Genetic diversity study of common bean (Phaseolus vulgarisL.) germoplasm from Ethiopia using inter simple sequence repeat (ISSR) markers. African Journal of Biotechnology,13, 3638–3649

Darkwa K, Ambachewa D, Mohammed H, Asfawa A, Blair MW .(2016). Evaluation of common bean ( Phaseolus vulgaris L.) genotypes for drought stress adaptation in Ethiopia. The Crop Jou rnal 4:367-376.

De Martinis, D.; Koyama, T.; Chang, C. (2015). Ethylene is all around. Front. Plant Sci., 6, 76.

DeEll JR, vanKooten O, Prange RK, Murr DP .(1999). Application of chlorophyll fluorescence techniques in postharvest physiology. Hort. Rev., 23: 69-107.

Dev J, Gupta VP . (1997). Common bean historic view and breeding strategy. Annals of Biology 13: 213 -219.

Dhillon R, Francisco R, Roach J,Upadhyaya S, Delwiche M.A .(2014). Continuous leaf monitoring system for precision irrigation management in orchard crops.Journal of Agricultural Machinery Science.;10 (4):267–272.

Directorate of Water Development (DWD) .(1995). Uganda Water Action Plan: Rapid Water Resources Assessment, Chicago.

Dutra, A. F.; Melo, A. S. de; Filgueiras, L. M. B.; Silva, A. R. F. da; Oliveira, I. M. de; Brito, M. E. B. de. (2015).Parâmetros fisiológicos e componentes de produção de feijão-caupi cultivado sob deficiência hídrica. Revista Brasileira de Ciências Agrárias, v.10, p.189-197,. https://doi.org/10.5039/agraria.v10i2a3912

Ecocrop (2013). Ecocrop database. FAO, Rome, Italy. http:// Ecocrop.fao.org/Ecocrop/srv/en/

Else, M.A.; Coupland, D.; Dutton, L.; Jackson, M.B. (2001).Hydraulic and chemical signaling in flooded and well-drained Castor oil (Ricinus communis L.) plants. Physiol. Plant., 111, 46–54.

Emam y, Shekoofa F, Salehi, Jalali, AH . (2010). Water Stress Effects on Two Common Bean Cultivars with Contrasting Growth Habits. College of Agriculture, Shiraz University, Shiraz, Iran, American-Eurasian J Agriculture & Environmental Science 9 (5): 495-499.

Emam Y., Seghatoleslami MJ. (2005). Crop yield: physiology and processes. 1st ed. Shiraz (Iran): Shiraz University Inc. p. 593 (in Farsi).

Emam, Y .(1985). Effects of N levels and moisture regimes on agronomic characteristics of four cultivars of dry beans (Phaseolus vulgaris L). M.Sc Thesis, Shiraz University Shiraz, Iran p. 41.

Emam, Y. & Seghatoleslami, M. (2005).Crop Yield: Physiology and Processes. Shiraz University Inc., Shiraz. Farsi.

Endres l, souza jl, teodoro i, marroquim pmg, santos cm and brito jed. (2010). Gas exchange alteration caused by water deficit during the bean reproductive stage. R Bras Eng Agríc Ambiental 14: 11-16.

Evans DE. (2004). Aerenchyma formation. New phytol.,161: 35-49

FAOSTAT. (2015). Food and Agriculture Organization at www.fao.org.

Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA .(2009). Plantdrought stress: effects, mechanisms and management. Agron Sustain Dev 29: 185-212.

Fenta, B.A., S.P. Driscoll, K.J. Kunert, and C.H. Foyer. (2011). Characterization of DroughtTolerance Traits in Nodulated Soya Beans: The Importance of Maintaining Photosynthesis and Shoot Biomass Under Drought-Induced Limitations on Nitrogen Metabolism. Journal of Agronomy and Crop Science 198:92-103.

Fikru, Mekonnen. (2007). Haricot ban (Phaseolus Vulgaris L.) variety development in the lowland areas of Wollo. Proceedings of the 2nd Annual Regional Conference on Completed Crops Research Activities 18 - 21 September 2007, Bahir Dar, Ethiopia, pp 86-93.

Folzer H, Dat J, Capelli N, Rieffel D, Badot PM .(2006). Response to flooding of sessile oak: An integrative study. TreePhysiol., 26: 759-766.

Fukao T, Kennedy RA, Yamasue Y, Rumpho ME .(2003). Genetic andbiochemical analysis of anaerobically-induced enzymes during seed germinationof Echinochloa crus-galli varieties tolerant and intolerant of anoxia. J Exp Bot54: 1421–1429

Girma Abebe. (2009). Effect of NP Fertilizer and Moisture Conservation on the Yield and Yield Components of Haricot Bean (Phaseolus Vulgaris L.) In the Semi-Arid Zones of the Central Rift Valley in Ethiopia. Advances in Environmental Biology, 3: 302-307.

Girma, S., Gong, Y. & Görg, H. (2009). What determines innovation activity in Chinese state-owned enterprises? The role of foreign direct investment. *World Development* 37(4): 866-873.

Gómez, O., (2004). Evaluation of Nicaraguan common bean(Phaseolus vulgaris L.) landraces. Doctor’s Dissertation. ISSN 1401-6249, ISBN 91-576-6762-4.

González, R.G.G. and I.T. Pacheco, (2006). Genetic manipulation of plants for increased drought tolerance. Adv. in Agri. and Food Biotech, 71(97): 81-7736-269-0.

Grant, O. M., Incoll, L. D., and McNeilly, T. (2005). Variation in growth responses to availability of water in Cistus albidus populations from different habitats. Funct. Plant Biol. 32, 817–829. doi: 10.1071/FP05020

Guajardo-Flores, D., Serna-Saldívar, S. O. & Gutiérrez-Uribe, J. A. (2013). Evaluation of the antioxidant and anti-proliferative activities of extracted saponins and flavonols from germinated black beans (Phaseolus vulgaris L.): Food chemistry, 141(2): 1497-1503

Gwathmey C.O., Hall A.E. (1992). Adaptation to midseason drought of cowpea genotypes with contrasting senescence traits. Crop Science 32:773–778.

Habte, E., Müller, L. M., Shtaya, M., Davis, S. J. & von Korff, M. (2014). Osmotic stress at the barley root affects expression of circadian clock genes in the shoot. *Plant, cell & environment* 37(6): 1321-1337.

Habtu A, Abiye T .(2009). Disease management in low land pulse progress and possibilities for unintegrated approach pp: 141.

Halcomb, M., (2003). Too much Water Kills More Plants than too little Water. The University of Tennessee Extension

Hasanuzzaman, M., K. Nahar, A, Rahman, J.A. Mahmud, M.S. Hossain and M. Fujita .(2016). Soybean production and environmental stresses. In: Miransari M. (ed) Environmental Stresses in Soybean Production: Soybean Production, Volume 2. Academic Press/Elsevier Inc., New York. USA. ISBN: 978-0-12-801535-3

Heschel, M. S. & Riginos, C. (2005). Mechanisms of selection for drought stress tolerance and avoidance in Impatiens capensis (Balsaminaceae). *American journal of botany* 92(1): 37-44.

Hongbo S, Zongsuo L, Mingan S, Shimeng S, Zanmin H .(2005). Investigation on dynamic changes of photosynthetic characteristicsof 10 wheat (Triticum aestivumL.) genotypes during two vegetativegrowth stages at water deficits. Colloids Surf B Biointerfaces 43:221–227.

Hu, Y.-Y., Zhang, Y.-L., Yi, X.-p., Zhan, D.-x., Luo, H.-H., Soon, C. W. & Zhang, W.-F. (2014). The relative contribution of non-foliar organs of cotton to yield and related physiological characteristics under water deficit. *Journal of Integrative Agriculture* 13(5): 975-989.

Hua YIY, Yong FD, Qiang XIE, Qing CF .(2006). Effects of waterlogging on the gas exchange, chlorophyll fluorescence and water potential of Quercus variabilis and pterocarya stenoptera. Chinese J. Plant Ecol., 30(6): 960-968.

Huijser, P. & Schmid, M. (2011). The control of developmental phase transitions in plants. *Development* 138(19): 4117-4129.

IturbeOrmaetxe I, Escuredo PR, Arrese-Igor C, Becana M (1998) Oxidative damage in pea plants exposed to water deficit or paraquat. Plant Physiol. 116: 173–181.

Jackson, B.E., Wright, R.D. & Gruda, N.(2009). Container medium pH in a pine tree substrate amended with peat moss and dolomitic limestone affects plant growth. Hort Sci., 44: 1983–1987

Jaleel, C. A., Manivannan, P., Wahid, A., Farooq, M., Al-Juburi, H. J., Somasundaram, R. & Panneerselvam, R. (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. *Int. J. Agric. Biol* 11(1): 100-105.

Jiang C-D, Jiang G-M, Wang X, Li L-H, Biswas DK, Li Y-G. (2006). Increased photosynthetic activities and thermostability of photosystem II with leaf development of ELM seedlings (Ulmus pumila) probed by the fast fluorescence rise OJIP.Environmental and Experimental Botany58(1–3):261–268.

Jongdee, B., S. Fukai, and M. Cooper. (2002). Leaf water potential and osmotic adjustment as physiological traits to improve drought tolerance in rice. Field Crops Research 76:153-163.

Kamara, A., A. Menkir, B. Badu-Apraku and O. Ibikunle. (2003). The influence of drought stress on growth, yield and yield components of selected maize genotypes. J. Agri. Sci. 141:43-50.

Katungi, E., Farrow, A., Chianu, J., Sperling, L., & Beebe, S. (2009). Common bean in Eastern and Southern Africa: A situation and outlook analysis. Cali: CIAT

Kebere Bezaweletaw, Ketema Belete and Prapa Sripichitt, (2006). Genetic gain in grain yield potential and associated agronomic traits in haricot bean (Phaseolu vulgaris L.). Kasetsart Journal (Natural Science), 40: 835-847

Kellman AW, Hill GD, Mckenzie BA .(2005). Variability in nodulation of Phaseolus vulgarisL. with different rhizobial strains. Agron NZ 35:57–65

Kelly JD. (2000). Remaking bean plant architecture for efficient production. Adv Agron;71:109–143.

Khan HR, Link W, Hocking TJ, Stoddard FL,( 2007). Plant Soil, , 292, 205.

Kiani-Pouya A, Rasouli F. (2014). The potential of leaf chlorophyll content to screen bread- wheat genotypes in saline condition. Photosyntetica52:288-300.

Kleine, S., and Mueller, C. (2014). Drought stress and leaf herbivory affect root terpenoid concentrations and growth of Tanacetum vulgare. J. Chem. Ecol. 40, 1115–1125. doi: 10.1007/s10886-014-0505-2

Koricheva, J., Larsson, S., Haukioja, E., and Keinänen, M. (1998). Regulation of woody plant secondary metabolism by resource availability: hypothesis testing by means of meta-analysis. Oikos 83, 212–226. doi: 10.2307/3546833

Krupa, K., Dalawai, N., Shashidhar, H. & Harinikumar, K. (2017). Mechanisms of drought tolerance in Sorghum: A Review. *International Journal of Pure and Applied Bioscience* 5(4): 221-237.

Kuai J, Liu ZW,Wang YH, Meng YL,Chen BL, Zhao WQ, etal. (2014). Waterlogging during flowering and boll forming stages affects sucrose metabolism in the leaves subtending the cotton boll and its relationship with boll weight. Plant Science An International Journal of Experimental Plant Biology.;223(2):79–98.

Kudoh, H., Ishiguri, Y. & Kawano, S. (1996). Phenotypic plasticity in age and size at maturity and its effects on the integrated phenotypic expressions of life history traits of Cardamine flexuosa (Cruciferae). *Journal of Evolutionary Biology* 9(5): 541-570.

Kumar, N. P., Kulwal, L., Balyan, H. S. and Gupta, P.K. (2006). QTL mapping for yield contributing traits in two mapping populations of bread wheat. Mol. Breed., 19: 163-177

Kusvuran S., Dasgan YH and Abak K. (2011). Responses of different melon genotypes to drought stress. Yüzüncü Yil University Journal of Agricultural Sciences. 21:209-219

Lawson, T. & Blatt, M. R. (2014). Stomatal size, speed, and responsiveness impact on photosynthesis and water use efficiency. *Plant physiology* 164(4): 1556-1570.

Legesse, D. G. Kumssa, T. Assefa, M. Taha, J. Gobena, T. Alemaw, A. Abebe, Y. Mohhamed and H. Terefe. (2006). Production and Marketing of White Pea Beans in the Rift Valley, Ethiopia. A Sub-Sector Analysis. National Bean Research Program of the Ethiopian Institute of Agricultural Research

Lei Y, YinC and Li C. (2006). Differences in some morphological, physiological, and biochemical responses to droughtstress in two contrasting populations of Populus przewalskii. Physiologia Plantarum, 127:182-191

Li H, Syvertsen JP, Stuart RJ, McCoy CW, Schumann AW, Castle WS .(2004). Soil and Diaprepes abbreviatus root weevil spatial variability in a poorly drained citrus grove. Soil Sci., 169: 650-662.

Li, H. Y. & Yang, Y. F. (2008). Phenotypic plasticity of life history characteristics: quantitative analysis of delayed reproduction of green foxtail (Setaria viridis) in the Songnen Plain of China. *Journal of integrative plant biology* 50(6): 641-647.

LiJ,Wei F,Wang C,Cheng Y,Yin J.(2006).Effects of waterlogging on senescence of root system at booting stage in winter wheat.Acta Agronomica Sinica.; 32(9):1355–1360

Lima EP, Silva EL .(2008). Temperatura-base, coeficientes de cultura e grausdia para cafeeiro arábica em fase de implantação. Revista Brasileira de Engenharia Agrícola e Ambiental 12: 266-273.

Liu, H., Sultan MARF, Zhao HX. (2013). The screening of water stress tolerant wheat cultivars with physiological ind ices. Global Journal Of Biodiversity Science And Management 3:211-218.

LiuYP,ShenS,PanYQ,ZhangL,LinS,XueYW,etal. (2014).Diurnal variation in leaf-air temperature difference and leaf temperature difference and the hybrid difference in maize under different drought stress. Journal of China Agricultural University.;19(5):13–21.

Lizana, C., Wentworth, M.,Martinez, P.J., Villegas, D., Meneses, R., Murchie, H.E., Pastenes, C., Lercari, B., Vernieri,P., (2006). Differential adaptation of two varieties of common bean to abiotic stress. Effects of drought on yield and photosynthesis. J. Exper. Bot., 57(3), 685-697.

Ludlow, M.M., Muchow, R.C., (1990). A critical evaluation of traits for improving crop yields in water-limited environments. Advances in Agronomy 43, 107-153.

Lynch, J. P. and Brown, K. M. (2012). New roots for agriculture: Exploiting the root phenome. Philos. Trans. R Soc. B367: 1598–604.

Mafakheri, A., Siosemardeh, A., Bahramnejad, B., Struik, P. & Sohrabi, Y. (2010). Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Australian journal of crop science* 4(8): 580.

Maggio, A.; S. Miyazaki; P. Veronese; T. Fujita; J.I Ibeas; B. Damsz; M.L. Narasimhan; P.M.Hasegawa; R.J. Joly and R.A. Bressan .(2002). Does proline accumulation play an active role in stress-induced growth reduction. Plant J., 31:699–712.

Malik AI, Colmer TD, Lamber H, Schortemeyer M .(2001). Changes in physiological and morphological traits of roots andshoots of wheat in response to different depths of waterlogging. Aust.J. Plant. Physiol., 28: 1121-1131.

Manavalan, L.P.; Guttikonda, S.K.; Tran, L.P.; Nguyen, H.T. (2009). Physiological and molecular approaches to improve drought resistance in soybean. Plant Cell Physiol., 50, 1260–1276.

Manivannan P., Abdul Jaleel C., Kishorekumar A., Sankar B., Somasundaram R., SridharanR., Panneerselvam R. (2007). Changes in antioxidant metabolism of Vigna unguiculata (L.) Walp. by propiconazole under water deficit stress. Colloids and Surfaces B: Biointerfaces 57:69-74.

Maxwell, K, Jhonson GN . (2000). Chlorophyll fluorescence- a practical guide. Journal of Experimental Botany 51:659-668.

Mekonnen F .(2007). Haricot ban (Phaseolus vulgaris L.) Variety development in the lowland areas of Wollo. 2nd Annual Regional Conference on Completed Crops Research Activities, Ethiopia, pp. 86-93.

Mielke MS, de Almeida AAF, Gomes FP, Aguilar MAG, Mangabeira PAO. (2003).Leaf gas exchange, chlorophyll fluorescence and growth responses ofGenipa americanaseedlings to soil flooding, Environmental and Experimental Botany.; 50:123–135.

Miller G., Suzuki N., Ciftci-Yilmaz S. et al.: (2010). Reactive oxygen species homeostasis and signalling during drought and salinity stresses. – Plant Cell Environ. 33: 453 467,.

Mitra J. (2001). Genetics and Genetic Improvement of Drought Resistance in Crop Plants. Curr Sci. 80:758-762.

MoARD (Ministry of Agriculture and Rural Development) .(2009). Crop Development. Issue No.3.Addis Ababa, Ethiopia.

Mohamed, M., N. Keutgen, AA. Tawfik, and G. Noga. (2002). Dehydration-avoidance responses of tepary bean lines differing in drought resistance. Journal of Plant Physiology 159:31–38

Mohammadian R, Moghaddam M, Rahimian H, Sadeghian SY .(2005). Effect of early season drought stress on growth characteristics of sugar beet genotypes. Turk J Agric For 29: 357-368

Molina JC, Moda-Cirino V, da Fonseca Junior NS, de Faria RT, Destro D. (2001). Response of common bean cultivars and lines to drought stress. Crop Breed Appl Biotechnol. 1:363–372

Muñoz-Perea, C. G., Allen, R. G., Westermann, D. T., Wright, J. L., & Singh, S. P. (2007). Water use efficiency among dry bean landraces and cultivars in drought-stressed and non-stressed environments. Euphytica, 155, 393–402.https://doi.org/10.1007/s10681-006-9340-z

Nguyen, D., Rieu, I., Mariani, C., and van Dam, N. M. (2016). How plants handle multiple stresses: hormonal interactions underlying responses to abiotic stress and insect herbivory. Plant Mol. Biol. 91, 727–740. doi: 10.1007/s11103-016-0481-8

Nicotra, A. B., Hermes, J. P., Jones, C. S., and Schlichting, C. D. (2007). Geographic variation and plasticity to water and nutrients in Pelargonium australe. New Phytol. 176, 136–149. doi: 10.1111/j.1469-8137.2007.02157.x

Nielsen, D.C., Nelson, N.O., (1998). Black bean sensitivity to water stress at various growth stages. Crop Science 38, 422-427.

Niki, T., Yoshida, S. & Sakai, A. (1978). Studies on chilling injury in plant cells I. Ultrastructural changes associated with chilling injury in callus tissues of Cornus stolonifera. *Plant and Cell Physiology* 19(1): 139-148.

Nounjan N., Nghia P.T., Theerakulpisut P.: (2012).Exogenous proline and trehalose promote recovery of rice seedling from saltstress and differentially modulate antioxidants enzymes and expression of related genes. –J. Plant Physiol. 169: 596-604,.

Pantuwan, G., S. Fukai, M. Cooper, S. Rajatasereekul, and J.C. O'Toole. (2002). Yield response of rice (Oryza sativa L.) genotypes to different types of drought under rainfed lowlands: Part 1. Grain yield and yield components. Field Crops Research 73:153-168.

Peak D, West JD, Messinger SM and Mott KA. (2004). Evidence for complex, collective dynamics and emergent, distributed computation in plants. PNAS 101: 918-922.

Pimentel, C., Hébert, G., & Silva, J. V. (1999). Effectes of drought on O2evolution and stomatal conductance of beans at the pollination stage. Environmental and Experimental Botany, 42, 155-162.

Pinto, R. S. & Reynolds, M. P. (2015). Common genetic basis for canopy temperature depression under heat and drought stress associated with optimized root distribution in bread wheat; Theoretical and Applied Genetics, 128(4): 575-585.

Pirasteh-Anosheh, H.; Saed-Moucheshi, A.; Pakniyat, H.; Pessarakli, M. (2016). Stomatal responses to drought stress.In Water Stress and Crop Plants; Wiley: Hoboken, NJ, USA,; pp. 24–40.

Pires AA, Araújo GAA, Miranda GV, Berger PG, Ferreira ACB, et al. (2004). Rendimento de grãos, componentes do rendimento e índice spad do feijoeiro (Phaseolus vulgaris L.) em função de época de aplicação e do parcelamento da aplicação foliar de molibdênio. Ciência agro técnica 28: 1092-1098.

Pociecha E, Koscielniak J, Filek W .(2008). Effect of root flooding and stage of development on the growth and photosynthesis of field bean ( Vicia faba L. minor). Acta Physiol. Plant, 30: 529-535.

Polania, J. A., Poschenrieder, C., Beebe, S., & Rao, I. M. (2016). Effective use of water and increased dry matter partitioned to grain contribute to yield of common bean improved for drought resistance. Frontiers in Plant Science,7, 1–10

Ramirez-Vallejo, P. & Kelly, J. D. (1998). Traits related to drought resistance in common bean. *Euphytica* 99(2): 127-136.

Ranawake, A. L., Dahanayaka, N., Amarasingha, U. S., Rodrigo, W. J., & Rodrigo, U. D. (2011). Effect of water stress on growth and yield of mung bean (Vignaradiata L.). Tropical Agricultural Research & Extension, 14, 201–204

Rao IM. (2001).Role of physiology in improving crop adaptation to abiotic stresses in the tropics: The case of common bean and tropical forages. In: Pessarakli M, editor. Handbook of Plant and Crop Physiology. 2nd ed. New York, NY, USA: Basel;. pp. 583-613

Rao, I. M. (2014). Advances in improving adaptation of common bean and Brachiaria forage grasses to abiotic stress in the tropics. In Pessarakli M (Ed.), Handbook of plant and crop physiology. (p. 847-889). Boca Raton: CRC Press.

Rao, I., Beebe, S., Polania, J., Ricaurte, J., Cajiao, C., Garcia, R. & Rivera, M. (2013). Can tepary bean be a model for improvement of drought resistance in common bean? *African Crop Science Journal* 21(4).

Rao, R., & Li, Y. (2003). Management of flooding effects on growth of vegetable and selected field crops. HortTechnology, 13(4), 610-616.

Ren BZ, Zhang JW, Li X, Fan X, Dong ST, et al. (2014). Effects of waterlogging on the yield and growth of summer maize under field conditions. Canadian Journal of Plant Science.; 94: 23–31

Ren, B., Zhang, J., Dong, S., Liu, P. & Zhao, B. (2016). Effects of waterlogging on leaf mesophyll cell ultrastructure and photosynthetic characteristics of summer maize. *PloS one* 11(9).

Riaz, A., A. Younis, A. Riaz Taj, A. karim, U. Tariq, S. Munir and S. Riaz, (2013). Effect of Drought Stress on Growth and Flowering of Marigold (Tagetes erecta L.). Pak. J. Bot., 45(1): 123-131.

Ribas-Carbo, M., N.L. Taylor, L. Giles, S. Busquets, P.M. Finnegan, D.A. Day, H. Lambers, H.l. Medrano, J.A. Berry, and J. Flexas. (2005). Effects of Water Stress on Respiration in Soybean Leaves. Plant Physiology 139:466-473.

Richards, R.A., (2006). Physiological traits used in the breeding of new cultivars for waterscarce environments. Agricultural Water Management 80, 197-211.

Richee, C. J. (2004). Identification of soybean cultivars toleranceto waterlogging through analyses of leaf nitrogen concentration (42 pages pp.) (MSc Thesis). Louisiana State University and Agricultural and Mechanical College, Baton Rouge, LA

Roel JW, Wanek BW and Hietz P. (2011). Stable carbon isotopes in tree rings indicate improved water use efficiency and drought responses of a tropical dry forest tree species. Trees 25: 103-113.

Romero P, Gil-Muñoz R, del Amor FM, Valdés E, Fernández JI,Martinez-Cutillas A .(2013). Regulated deficit irrigation based upon optimum water status improves phenolic composition in Monastrell grapes and wines. Agrc Water Manag 121:85–101. doi:10.1016/j.agwat.2013.01.007

Rosales Serna RJ, Kohashi Shibata JA, Acosta Gallegos CT, Lopez J, Ortiz Cereceres JD, et al. (2004). Biomass distribution, maturity acceleration and yield in drought-stressed common bean cultivars. Field Crops. Research 85: 203-211

Rosales, M.A., Ocampo, E., Rodríguez-Valentín, R., Olvera-Carrillo, Y., Acosta-Gallegos, J.,Covarrubias, A.A., (2012). Physiological analysis of common bean (Phaseolus vulgarisL.) cultivars uncovers characteristics related to terminal drought resistance. Plant Physiology and Biochemistry 56:24–34.

Saeedipour S. (2011). Effect of drought at the post -anthesis stage on remobilization of carbon reserves in two wheat cultivars differing in senescence properties. African Journal of Biotechnology 10:3549-3557.

Sairam, R., Kumutha, D., Ezhilmathi, K., Deshmukh, P.S. and Srivastava, G.C. (2008). Physiology and biochemistry of waterlogging tolerance in plants. Biol. Plant. 52: 401-412.

Saleem M, Ashraf M, Akram NA . (2011). Salt (NaCl)- induced modulation in some key physio-biochemical attributes in okra (Abelmoschus esculentusL.). J. Agron. Crop Sci., 197: 202-213.

Saleh, S., Liu, G., Liu, M., Ji, Y., He, H., & Gruda, N. (2018). Effect of irrigation on growth, yield, and chemical composition of two green bean cultivars. Horticulturae, 4(3), 1-10. https://doi.org/10.3390/ horticulturae4010003

Sánchez-Rodríguez E., del Mar Rubio-Wilhelmi M., Blasco B. et al.: (2012). Antioxidant response resides in the shoot in reciprocal grafts of drought-tolerant and drought-sensitive cultivars in tomato under water stress. –Plant Sci. 188-189: 86-96,.

Santos MG, Ribeiro RV, Machado EC, Pimentel C, (2009). Biol Planta, 53, 229.

SAS Institute Inc. Cray. (2008). Users Guide. Version 9.2. NC.USA.

Schlichting, C. D. & Pigliucci, M. (1998). Phenotypic evolution: a reaction norm perspective. Sinauer Associates Incorporated.

Schlichting, C. D. & Pigliucci, M. (1998). *Phenotypic evolution: a reaction norm perspective.* Sinauer Associates Incorporated.

Seki, M., Umezawa, T., Urano, K., Shinozaki,K., 2007. Regulatory metabolic networks in drought stress responses. Current opinion in plant biology 10, 296-302.

Setter TL,Waters I,Sharma SK,Singh KN,Kulshreshtha N,Yaduvanshi NPS,et al. (2009).Review of wheat improvement for waterlogging tolerance in Australia and India:the importance of an aerobiosis and element toxicities associated with different soils.Annals of Botany.;103(2):221–235.

Seversike TM, Sermons SM, Sinclair TR, Carter JR TE and Rufty TW. (2013). Temperature interactions with transpiration response to vapor pressure deficit among cultivated and wild soybean genotypes. Physiol Plant 148: 62-73.

Shao, H. B., Chu, L. Y., Shao, M. A., Jaleel, C. A. & Hong-mei, M. (2008). Higher plant antioxidants and redox signaling under environmental stresses; Comptes rendus biologies, 331(6): 433-441

Shaw, R. E. (2015).Plant waterlogging: causes, responses, adaptations and crop models.

Shenkut AA, Brick MA .(2003). Traits associated with dry edible bean (Phaseolus vulgaris L.) productivity under diverse soil moisture environments. Euphytica 133: 339-347

Silva CDS, Santos PAA, Lira JMS, Santana MC, Silva CD .(2010). Curso diário das trocas gasosas em plantas de feijão-caupi submetidas a deficiência hídrica. Revista Caatinga 23: 7-13.

SILVA, E. F. et al. (2013).Avaliação de cultivares de feijão-caupi irrigado para produção de grãos verdes em Serra Talhada - PE. Revista Caatinga, v. 26, n. 1, p. 21-26.

Silverside TM, sermons SM, sinclair TR, carter JR TE and rufty TW. (2013). Temperature interactions with transpiration response to vapor pressure deficit among cultivated and wild soybean genotypes. physiol plant 148: 62-73.

Singer SM, Helmy YI, Karas AN, Abou-Hadid AF .(1996). Growth and development of bean plants (Phaseolus vulgaris L.) grown under water-stress. Cahiers Options Mediterraneennes, 31:241-250.

Singh S.K., Raja Reddy K. (2011). Regulation of photosynthesis, fluorescence, stomatal conductance and water-use efficiency of cowpea (Vigna unguiculata [L.] Walp.) under drought. Journal of Photochemistry and Photobiology B: Biology 105:40 -50.

Singh, S.P. and H.F. Schwartz. (2010), “Breeding common bean for resistance to diseases: A review”, Crop Science, Vol. 50, No. 6, pp. 2 199-2 223, http://dx.doi.org/10.2135/cropsci2009.03.0163.

Singh, (1995).Selection for water-stress tolerance in interracial population of common bean, Crop Sci. 35:153–165

Smethurst CF, Garnet T, Shabala S .(2005). Nutrition and chlorophyll fluorescence responses of lucerne (Medicago sativa) to waterlogging subsequent recovery. Plant Soil, 270(1–2): 31-45.

Solaiman Z, Marschner P, Wang D, Rengel Z . (2007). Growth, P uptake and rhizosphere properties of wheat and canola genotypes in an alkaline soil with low P availability. Biology and Fertility of Soils44, 143–153.

Solanki ,J.K.;Sarangi,S.K. (2015). Effect of drought stress on proline accumulation in peanut genotypes. Int. J. Adv.Res., 2, 301–309.

Soratto, R. P., Orivaldo, A. R. F., Rodrigues, R. A. F., Buzetti, S., & Silva, T. R. B. (2003). Resposta do feijoeiro ao preparo do solo, manejo de água e parcelamento do nitrogênio. Acta Scientiarum: Agronomy, 25, 89-96.

Strasser, R. J., Tsimilli-Michael, M. & Srivastava, A. (2004). Analysis of the chlorophyll a fluorescence transient. *Chlorophyll a Fluorescence*: 321-362.

Subbarao, G.V., Johansen, C., Slinkard, A.E., Nageswara, R.C., Saxena, N.P., Chauhan, Y.S., (1995).Strategy for improving droughtresistance in grain legumes. Criti. Rev. PlantSci., 14, 469-523.

Sucre B., Suarez N.: (2011). Effect of salinity and PEG-induced water stress on water status, gas exchange, solute accumulation, and leaf growth in Ipomoea pescaprae. –Environ. Exp. Bot. 70: 192-203,.

Suzuki, N., Rivero, R. M., Shulaev, V., Blumwald, E., and Mittler, R. (2014). Abiotic and biotic stress combinations. New Phytol. 2003, 32–43. doi: 10.1111/nph.12797

Szilagyi, L. (2003). Influence of drought on seed yield components in common bean. *Bulgarian Journal of Plant Physiology* 2003(spl issue): 320-330.

Taiz L, Zeiger E .(2002). Plant Physiology, 3rd Edn. Sinauer Associates, Inc. Sunderland, USA. 647 pp.

Taiz, L., & Zeiger, E. (2009). Fisiologia vegetal (4 ed.). Porto Alegre: ARTMED. 848 p

Taiz, L., Zeiger, E., Moler, I. & Murphy, A. (2015). Plant physiology and development (Sinauer As). *Sunderland, MA, USA.*

Tar'an, H., Singh, P.S., (2002). Comparison of sources and lines selected for drought resistance in common bean: Crop breeding, genetics & cytology. CropSci., 42, 64-70.

Tardieu, F., Parent, B., Caldeira, C. F. & Welcker, C. (2014). Genetic and physiological controls of growth under water deficit; Plant Physiology, 164(4): 1628-1635

Tepwadee, C., M. Shigenori, J. Abe, I. Kaori, T. Ryosuke and P. Anan, (2008). Root at seedling stage of Three Cordage Fiber Crops. Plant Prod. Sci., 1(2): 232-237.

Thomas, A., S. Guerreiro and L. Sodek. (2005). Aerenchyma formation and recovery from hypoxia of the flooded root system of nodulated soybean. Annals of Botany 96: 1191-1198.

Tilahun, A., Kimani, P., Ronno, W., Lunze, L., Mbikayi, N., (2004). Coping with drought prone regions of Africa. CIAT Occational Publication series 38.

Toai, T. T., Hoa, T. T., Hue, N. T., Nguyen, H. T., Shannon, J. G., & Rahman, M. A. (2010). Flooding tolerance of soybean [Glycine max (L.) Merr.] Germplasm from Southeast Asia under field and screen-house environments. The Open Agriculture Journal, 4, 38–46

Todaka, D.; Shinozaki, K.; Yamaguchi-Shinozaki, K. (2015).Recent advances in the dissection of drought-stress regulatory networks and strategies for development of drought-tolerant transgenic rice plants. Front. Plant Sci., 6, 84.

Tsai, S.-L., Chu, T.-M. & Kuo, C. (1992).Waterlogging effects on nitrogen uptake and metabolism in corn. In *Adaptation of food crops to temperature and water stress: proceedings of an international symposium, Taiwan*, 13-18.

Turner NC. (1981). Techniques and experimental approaches for the measurement of plant water status. Plant and Soil. ;58(1-3):339-366

Turner, N.C., (2003). Drought resistance: a comparison of two research frameworks. In: Saxena, N.P. (Ed.), Management of agricultural drought: agronomic and genetic options. Science Publishers, Inc., Enfield, pp. 89-102

Uddin, S., Parvin, S., & Awal, M. A. (2013). Morpho-physiological aspects of mungbean (vignaradiata L.) in response to water stress. International Journal of Agricultural Science and Research, 3, 137–148

Unkovich M, Herridge D, Peoples M, Cadisch G, Boddey B, Giller K,Alves B, Chalk P .(2008). Measuring plant-associated nitrogen fixation in agricultural systems. ACIAR. Monograph no 136, Canbberr

V. Chekanai, R. Chikowo, B. Vanlauwe:(2018). Agriculture, Ecosystems and Environment 266: 167–173

Vadez, V. (2014). Root hydraulics: the forgotten side of roots in drought adaptation. Field Crops Research, 165, 15-24.

Van Dam, N. M. (2009). Below ground herbivory and plant defenses. Annu.Rev. Ecol. Evol. Syst. 40, 373–391.

Vendruscolo, A.C.G; I. Schuster; M. Pileggi; C.A.Scapim; H.B.C. Molinari; C.J. Marur and L.G.C.Vieira .(2007). Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat. J. Plant Physiol., 164(10):1367-1376.

Via, S., Gomulkiewicz, R., De Jong, G., Scheiner, S. M., Schlichting, C. D. & Van Tienderen, P. H. (1995). Adaptive phenotypic plasticity: consensus and controversy. *Trends in Ecology & Evolution* 10(5): 212-217.

Wagara, I. N. & Kimani, P. M. (2007). Resistance of nutrient-rich bean varieties to major biotic constraints in Kenya; In *African Crop Science Conference Proceedings* Vol. ***8***, pp. 2087-2090.

Waldhoff D, Furch B, Junk WJ. (2002). Fluorescence parameters, chlorophyll concentration and anatomical features as indicators for flood adaotation of an abundant tree species in Central Amazonia:Symmeria paniculata, Environmental and Experimental Botany.; 48: 225–235

Walelign W. (2015).Haricot bean production goude: With emphasis on southern Ethiopia (English version).27-33

Wang YT, Zhou YF,Li FX,Su Z,HanY,Gao MY,et al. (2013).Relationship between leaf temperature and water status in sorghum under drought stress. Agricultural Research in the Arid Areas. 31(6):146

Weemstra, M., Mommer, L., Visser, E. J. W., van Ruijven, J., Kuyper, T. W.,Mohren, G. M. J., et al. (2016). Towards a multidimensional root trait framework: a tree root review. New Phytol. 211, 1159–1169. doi: 10.1111/nph.14003

White JW, Castillo JA. (1992). Evaluation of diverse shoot genotypes on sele cted root genotypes of common bean under soil water deficits. Crop Science 32:762-765.

White, J, Singh SP. (1991). Sources and inheritance of earliness in tropically adapted indeterminate common bean. Euphytica.; 55:15-19

Wortmann, C.S. (2006), "Phaseolus vulgarisL. (Common bean): Prota 1: Cereals and pulses/Céréalesetlégumessecs"http://database.prota.org/PROTAhtml/Phaseolus%20vulgaris%20(common%20bean)_En.htm.

Wu, C. A., Lowry, D. B., Nutter, L. I. & Willis, J. H. (2010). Natural variation for drought-response traits in the Mimulus guttatus species complex. *Oecologia* 162(1): 23-33.

Wullschleger, S., Yin TM, Difazio SP, Tschaplinski TJ, Gunter LE,Davis MF, Tuskan GA .(2005). Phenotypic variation in growth and biomass distribution for two advanced-generation pedigrees of hybrid poplar. Canad J Forest Res 35: 1779-1789.

Xia JR, Li YJ, Zou DH. (2004). Effects of salinity stress on PS II in Ulva lactuca as probed by chlorophyll fluorescence measurements.Aquatic Botany80(2):129–137DOI 10.1016/j.aquabot.2004.07.006

Xiong, L., R.-G. Wang, G. Mao, and J.M. Koczan. (2006). Identification of Drought Tolerance Determinants by Genetic Analysis of Root Response to Drought Stress and Abscisic Acid. Plant Physiology 142:1065-1074.

Xu, R., Dai, W. Luo, X. Yin, Y. Li, X. Tai, L. Han, Y. Chen, L. Lin, G. Li, C. Zou, W. Du, and M. Diao. (2010). A photothermal model of leaf area index for greenhouse crops. Agr. For. Meteorol. 150:541–552.

Xu, Z., Zhou, G. (2008).Responses of leaf stomatal density to water status and its relationship with photosynthesis in a grass. J. Exp. Bot., 59, 3317–3325.

Rezene,Y., Gebeyehu,S., Zelleke, H. (2011).Genetic variation fordrought resistance in small red seeded common beangenotypes, Afr. Crop. Sci. J. 19:303–312

Yadollahi, A., Arzani K, Ebadi A, Wirthensohn M, Karimi S .(2011).The response of different almond genotypes to moderate and severe water stress in order to screen for drought tolerance. Sci Hort 129: 403–413.

Yamauchi, T., Colmer TD, Pedersen O,Nakazono M. (2018). Regulation of root traits for internal aeration and tolerance to soil waterlogging flooding stress. Plantphysiology.; 176(2):1118–1130.

Yang, S., Pang, E., Ash, E., Huttner, E., Zong, E.X., Kilian, E.A. (2006). Low level of genetic diversity in cultivated Pigeonpea compared to its wild relatives is revealed by diversity arrays technology. Theory. Appl. Genet.,113, 585–595.

Yordanova, R. Y. & Popova, L. P. (2007). Flooding-induced changes in photosynthesis and oxidative status in maize plants. *Acta Physiologiae Plantarum* 29(6): 535-541.

Zhang, R., Li, J., Guo S.R. et al.: (2009). Effects of exogenous putrescine on gas exchange characteristics and chlorophyll fluorescence of NaCl-stressed cucumber seedlings. –Photosynth. Res. 100: 155-162.

Zhou, W. and Lin, X. (1995). Effects of waterlogging at different growth stages on physiological characteristics and seed yield of winter rape (Brassica napus L.). Field Crops Res. 44: 103-110.

Zlatko Stoyanov, Z. (2005). Effects of water stress on leaf water relations of young bean plants. *Journal of Central European Agriculture* 6(1): 5-14.

# 7. APPENDICES

Appendix Table 1. Mean square values for crop phenology and growth attribute as affected by varieties, moisture level and interaction effects of varieties and moisture level in 2019

| | Mean square | | | | |
|---|---|---|---|---|---|
| **Parameters** | Varieties(V) | Moisture level(ML) | V*ML | Error | CV (%) |
| Days to flowering | 389.20*** | 62.60*** | 28.60*** | 0.6 | 2.08 |
| Days to pod formation | 263.13*** | 233.62*** | 90.23*** | 0.57 | 1.69 |
| Days to maturity | 13.08*** | 25.48*** | 6.48*** | 1.97 | 1.63 |
| Leaf fresh weight | 24.703*** | 162.741*** | $3.577^{ns}$ | 2.415 | 16.36 |
| Leaf dry weight | 0.362** | 5.8457*** | 0.2419ns | 0.1238 | 18.01 |
| Leaf number | 5012.84*** | 1886.32*** | 187.65** | 62.22 | 14.02 |
| Leaf area | 21670ns | 384497*** | 11932ns | 15273 | 23.44 |
| Plant height | 5012.84******* | 1886.32******* | 187.65****** | 62.22 | 14.02 |
| Root length | 98.79*** | 1263.77*** | 71.54*** | 14.56 | 13.30 |
| Internode length | 140.844*** | 35.770*** | 3.364ns | 1.884 | 18.43 |
| Stomata number | 60.411*** | 4.8667ns | 4.144ns | 8.2095 | 22.27 |
| Epidermal cell number | 354.967*** | 21.622ns | 46.650ns | 41.422 | 18.26 |
| Stomata width | 0.39441** | 0.02657ns | 0.0349ns | 0.0284 | 16.02 |
| Stomata length | 0.09288** | 0.00388ns | 0.0153ns | 0.01190 | 17.64 |

The sign **, *** and ns indicates; Significant at 5% and 1% and non-significant probability level (P>0.05), respectively.

Appendix Table 2. Mean square values for crop physiology, grain yield and yield component as affected by varieties, moisture level and interaction effects of varieties and moisture level in 2019

| | Mean square | | | | |
|---|---|---|---|---|---|
| **Parameters** | Varieties(V) | Moisture level(ML) | V*ML | Error | CV (%) |
| Photosynthesis rate | 33.27*** | 1365.02*** | 36.06*** | 0.60 | 26.85 |
| Transpiration rate | 0.3298ns | 19.3578*** | 0.7169** | 0.2970 | 20.02 |
| Stomata conductance | 0.74159*** | 8.36920*** | 0.8195*** | 0.04442 | 23.17 |
| Water use efficiency | 10.405*** | 121.978*** | 10.474*** | 0.746 | 22.80 |
| Proline | 0.13632*** | 0.07734** | 0.01646** | 0.02184 | 34.70 |
| Relative water content | 38.984ns | 667.908*** | 47.783ns | 71.323 | 11.12 |
| Chlorophyll a | 0.8337ns | 14.7413*** | 1.2601** | 0.4438 | 7.55 |
| Chlorophyll b | 1.3367ns | 40.9555*** | 2.2940*** | 0.6451 | 13.33 |
| Chlorophyll (a+b) | 3.166** | 104.728*** | 5.433*** | 0.981 | 6.67 |
| Fv/Fm | 5.053*** | 2.879*** | 3.609** | 1.031 | 1.25 |
| Pods per plant | 3.0359** | 40.8212*** | 0.9031ns | 0.9802 | 25.85 |
| Seeds per plant | 36.958** | 603.383*** | 21.328ns | 10.054 | 26.08 |
| Grain yield per plant | 3.958** | 108.212*** | 1.255ns | 1.006 | 21.53 |
| Harvest Index | 242.29ns | 3512.08*** | 473.49** | 164.23 | 28.33 |
| Leaf temperature | 1.9571*** | 28.1518*** | 0.3178** | 0.1264 | 1.43 |

The sign **, *** and ns indicates; Significant at 5% and 1% and non-significant probability level (P>0.05), respectively.

Figure 7.Common bean varieties under control treatment

Figure 8.Common bean varieties under water-logging stress treatment

Figure 9. Common bean varieties under drought stress treatment

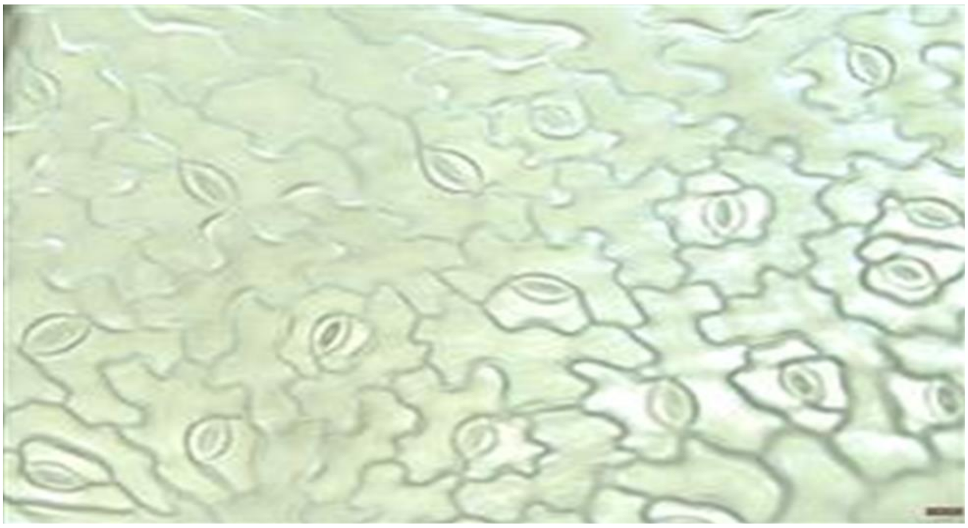

Figure 10.Stomata anatomy of common bean under control treatment

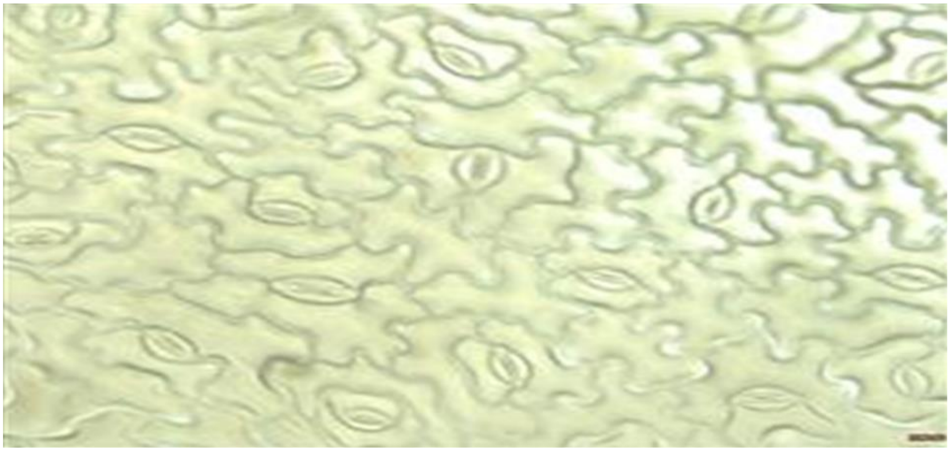

Figure 11.Stomata anatomy of common bean under water-logging treatment

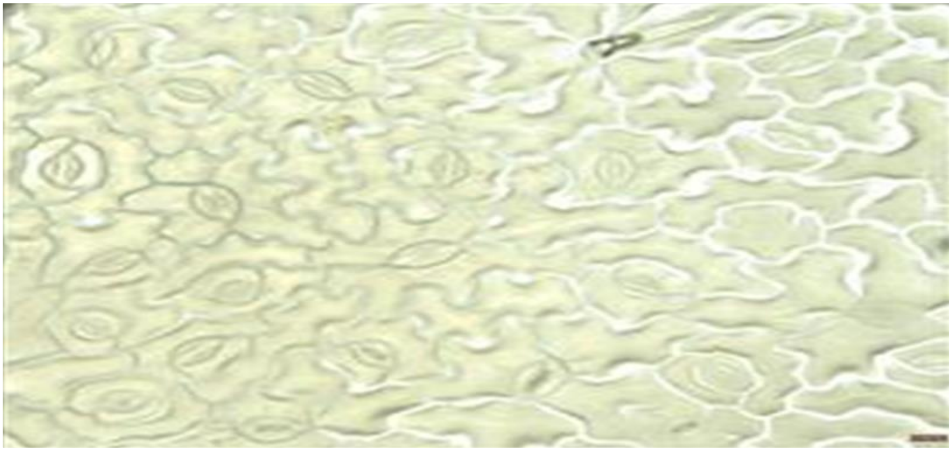

Figure 12.Stomata anatomy of common bean under drought stress

# SKETCH OF BIOGRAPHY

The author, Refisa Jebessa Geleta was born on March 3, 1992 GC at Gidda Ayana Province of East Wollega Zone, Oromia regional state, Ethiopia. At age 7 he admitted to grade 1 in 1999 GC and completed his primary education (1-8) at Jangir primary school. Then after, he attended his high school (9-10) and preparatory school (11-12) at kiremu secondary school and Gidda Ayana preparatory school, respectively. After completion of University entrance examination, he joined Ambo University in November 2012 to pursue his first Degree and graduated with BSc Degree in Horticulture in July 2015. After his graduation, he had worked at Agarfa ATVET College for one year as an instructor. In 2017, he came back to Ambo University and has been employed as a Graduate assistant. After serving one year at Ambo University, he has got a chance to attend his Master's program. In 2018, he joined the Graduate program in Horticulture at Hawassa University.