Unraveling the Constraint of Lentil Productivity through Improved Agronomic Management for Sustainable Production in Ethiopia: A review

Gebrekidan Feleke*[1], Almaz Meseret[1] and Bizuwork Tafes[1]
[1]*Ethiopian Institute of Agricultural Research (EIAR), Debre Zeit Agricultural Research Center (DZARC), Debre Zeit, Ethiopia:* ***Corresponding author:** gebrekidan336@gmail.com

Abstract

Lentil is the most vital grain legume crop in Ethiopia and ranking first in consumers' preference. It is primarily cultivated in the central highlands of Ethiopia during the main cropping system, with little care and management. There are significant limitations on the growth and production of lentil, which include lack of sufficient information, inherent lower output capacities of the local crops as well as unpredictable output due to various biotic and abiotic factors. As a result, researchers and farmers are facing a significant challenge in increasing lentil production to meet the national demand. Therefore, more focus needs to be paid to develop and encourage low-cost lentil production. Improved crop management practices, integrated soil fertility, and integrated pest, management, etc., that are not only increase productivity and profitability, but also ensure environmental and social sustainability besides nutritional security , are among the most potential technologies of lentil production. Thus, this review paper provides a critical assessment of the contribution of various improved agronomic practices to improve lentil productivity on one hand, while also highlighting future research priorities on the other, with the prime objective of ensuring lentil production in Ethiopia.

Keywords: agronomic practices, lentil, productivity, sustainability

Introduction

Agriculture is the backbone of Ethiopia's economy with diversification and intensification of farming systems because of the varied agro-ecologies that sustain its agricultural production and conserve the rich biodiversity of the region (World Bank, 2016). Agriculture contributes 42 percent of GDP and employs about 85 percent of the population who earn their living directly or indirectly from it (CSA, 2016), but how, when, and where to cultivate are the key issues that farmers and land managers face daily. On the other hand, Ethiopian farming is dominated by a rainfed scheme, which accounts for approximately 97 percent of the current cropland area and is widely regarded as a low-yield system (Korbu *et al.*, 2020). The Ethiopian agriculture system generally subsistence primarily for the majority of essential food crops, including lentils (Negussie, 2004). Thus, farmers grow a variety of legume crops for food and feed, as well as to earn money and, more importantly, to restore cropland fertility. Farmers' involvement in legume growing has risen almost twice over the last 20 years, increasing from 4.5 to 8.5 million farmers (Atnaf *et al*., 2015). Besides legumes have high protein content, they are economically and environmentally beneficial to use atmospheric nitrogen through biological nitrogen fixation (BNF) (Yirga *et al.,* 2016).

Lentil is among the principal grain legumes in the highland Vertisols of Ethiopia mainly involved in tef, wheat, and barley-based crop rotation systems. In this cropping system, the function of yield increment of the following cereal crop is realized as a result of the predecessor lentil that fixes nitrogen, as well as breaks the life cycle of essential diseases, insect pests, and weed populations (Geletu, 2006). Lentil is grown and harvested primarily in Ethiopia's northern, central, and eastern highlands mainly during the rainy season ('kiremt', June-December) and to some extent during the short rainy season (*'belg'*, February-May). In Ethiopia, lentil ranks 6th in terms of the number of growers; accounting for, 8.7% of total pulse growers, area, i.e., 0.79% of the total area under pulse crops and production for 0.45% of total pulse production (CSA, 2019). Over the last three decades, the production of lentils in Ethiopia showed an increasing trend regardless of the static nature of the area under cultivation (Figure. 1b). The annual growth rate, however, is lower than the other highland food legume crops in the country. Currently, the productivity of lentils has gone up to 1.4 t ha^{-1}, doubling since 1992 (Figure.1a). However, lentil production still faces numerous constraints due to pests, diseases and agroclimatic stresses, the lack of improved inputs, mechanization, and proper agronomic management (Frehiwot, 2009).

In Ethiopia, lentil research began on a small scale in the 1970s as a result of work by the National Committee for Crop Improvement, but efforts were intensified after the upgrading of the National Chickpea and Lentils Improvement Program in 1978 (Fikre & Bekele, 2020). Many research activities have been done so far to identify the agronomic requirement for the production of lentils and several site-specific studies have been carried out. However, much of the findings and information generated have been given less recognition by the users. Furthermore, the findings and research reports have not been adequately evaluated and not systematically reviewed in a usable manner. These papers, therefore, aims at reviewing and compiling the scattered findings of agronomic practices on lentil in the past decades and identifies the major yield gap and suggest future research direction.

Materials and Methods

This review applied reporting items for systematic literature review approach to search and select past and current publications relevant to the topic. The development of this review paper is based on the use of selected published articles in journals, proceedings, research centers annual reports, and technical reports available on the subject area that have been conducted by various researchers, institutions, and organizations from early 1970 until now.

Result and Discussion

Socio-economic significance of lentil

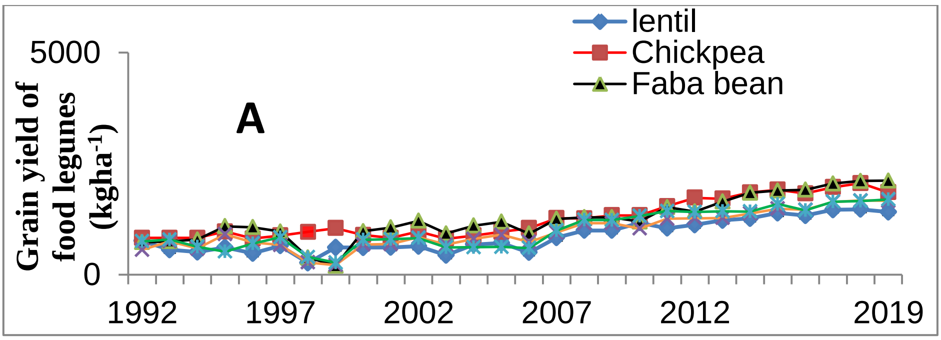
Ethiopian farmers in the agricultural system have been using grain legumes like chickpea, lentil, fababean common bean etc for many years to maintain soil fertility due to the capacity of the crops to fix atmospheric nitrogen in the soil. This reduces fertilizer costs in subsequent cereal crops and increases yields (Mashungwa *et al*., 2019). Lentil has major economic and ecological functions in Ethiopian low-input agriculture. The crop is mainly grown as a cash crop by smallholder farmers at the highest price in local markets in comparison to other food crops. Lentil is also one of the main pulse export crops that generate departmental income at the macro-level (Ferede *et al.*, 2014). Since 1997, Ethiopia has exported several lentil volumes to different areas of the world, with the lentil amount and value greatly increased until 2009. However, the trend in lentil amount and value has decreased since 2009 (Eyob & Baye, 2019).

Like many other food legumes, lentil is a valuable protein, and products contain no anti-nutrition or toxicity. It is the main pulse crop used as food in the country. whole seed or split seed is fried to produce a wot, which is consumed with injera. Lentil is a major component in making Sambusa' in Ethiopia. The dry seed consists of 25.0% protein, 1.0% fat, and 55.8% carbohydrate. From the fats, 82% are unsaturated fats, while 18% are saturated. From 100grams of lentil, we can get 353 kcal energy, 10.7 grams of dietary fiber, and though not complete, some amount of all the nine essential amino acids ranging from 0.22 to 2.05 grams. Also, 100-gram lentil meets the 76% Thiamine vitamin B1, 43% Pantothenic acid B5, 42% of vitamin B6, 100% of Folate vitamin B9, and 50% of our daily dietary requirement, assuming we have a daily need of 2000 calories (Edwards et al., 2019).

Due to its capacity to fix nitrogen, lentil enhances soil health, long-term soil fertility, and sustainable crop systems in cereals in the highlands of Ethiopia (Yirga *et al.*, 2016). Besides, lentils can be used to feed livestock, particularly poultry, although they are mostly human feeding. The walls of the stroke and pod have a high feed weight, the waste from threshing. According to Mersha & Lemessa (2019), the nutritional values of lentil haulm including crude protein (6.9-8.1%), neutral detergent fiber (49.5-52.0%), metabolizable energy (8.0-8.2%), Ash (9.4-9.8 MJ kg-1), acid detergent fiber (36.8-38.0%) and in vitro organic matter digestibility (54.8-55.3%), which favors optimum feed intake and stimulating rumen function and cud-chewing for ruminant livestock.

Overview of lentil production constraints in Ethiopia

Due to increasing domestic demand, export potential, and high economic return, the area harvested for lentil increased from 39 thousand hectares in 1992 to 289 thousand hectares in 2019, increased by 86% (Fig.1b), it shows an increasing trend from 1992 to 2019 years. However, in the last five years (2014 to 2019) the area harvested for lentils has decreased by 30% and unfortunately, it was down by 47.5% in 2018 as it is compared to its previous year. The national productivity of lentils also shows an increasing trend starting from 1992 till 2019 as one can look in Figure 1a. However, Ethiopia's overall lentil production is lower than the average of the top five nations, owing to varieties of constraints (Fig.1a). The major constraints for the slow growth rate of lentil production and productivity are briefly discuses as follows:



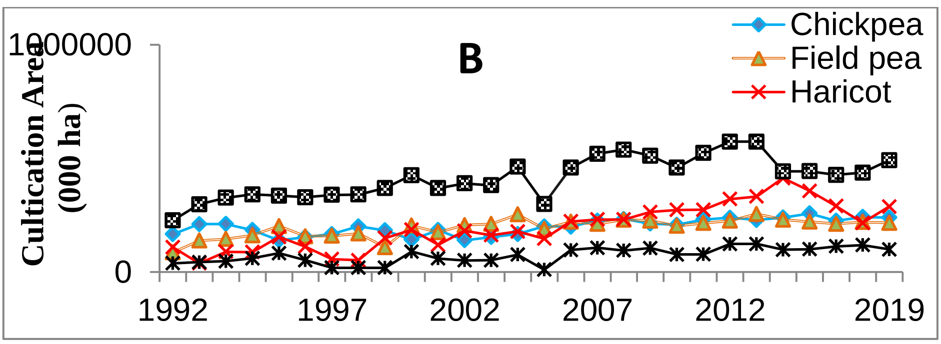


Fig 1 a & b. Ethiopian food legume production and productivity trends: (A) Region under cultivation of large food legumes grown in Ethiopia (Source: CSA (1992-2019)); (B) grain productivity (kg ha^{-1})

Agro-climate conditions and cropping systems in which lentil is cultivated differ across growing regions in Ethiopia. The productivity of this crop in this situation, therefore, depends on rainfall between mid-June and mid-October (Telaye *et al.,* 1994). Lentil is one of the main highland pulses and is suggested planting in mid to high-altitude areas of Ethiopia from late June to mid-July (Mebrate Tamrat & Admasu, 2018). Vertisols, on the other hand, are valuable agricultural soil in Ethiopia's highlands, where they are productive but difficult to maintain due to inadequate internal drainage and consequent waterlogging. As a result, the soil has inadequate aeration, lower soil microbial activity, depletion and unavailability of plant nutrients, and poor workability, all of which negatively impact crop growth, owing to reduced oxygen supply to the roots (Mekonen *et al*., 2013). Lentil is the most sensitive to waterlogging (Singh *et al.,* 2013). Waterlogging during germination can cause unsuccessful germination, late emergence, and suppression of root growth and at the vegetative stage can induce root system damage and lead to extensive leaf senescence and desiccation (Nessa *et al.,* 2013). Similarly, lentil is most susceptible to waterlogging at flowering and lead to flowers and pods abortion, retarded growth, and leaf senescence (turning from yellow to red). The crop will also face a rapid rise or lower in temperature and depleting soil moisture at grain filling stage, causing forced maturity. Dry and thermal seeds are normal in moisture stress areas during the seeding and blooming phases, intermediate drought during the crop season, and terminal drought and fire.

Lentil is mostly produced by smallholder farmers most of them follow conventional farming method based on indigenous knowledge. (Frehiwot, 2009). With this type of agriculture, the common agronomic practices of lentils mostly done by manual and seed handling and cleaning operations are not mechanized, even their produced grains/seeds are mostly consumed on-farm or sold to local markets. Farmers usually planted lentil in early July to mid-September and harvested without weeding at any stage of crop growth. Seeding rates are also extremely low: 30-35 kg^{-1}. However, research recommendations are a minimum of 50 kg ha^{-1} for small size lentils (Telaye *et al*., 1994). Moreover, farmers have never used fertilizer in food lentil production. Instead, this crop is used as the restorer of soil fertility for the following cereal crops. Threshing is done either through trampling by cattle or horses or in some sectors by groups of men or women who beat the dried plants with sticks. Winnowing is also done by throwing the chaff in the air on a windy day with a wooden fork or by hand. As a result, the returns from the above agricultural practices for lentil production are very low (Telaye *et al*., 1994).

Lentil is susceptible to a high prevalence of disease and insect pests .

The most common biotic factors causing the loss of lentil yield are the lentil wilt/root rot cluster, Ascochyta blight, and rust (Ahmed and Ayalew, 2006; Negussie *et al.*, 2006). Some insect-pests attack lentil during the various stages of development and cause damage by defoliation, tunneling of stems and pods, flowers, and floral parts. This may result in poor plant growth, losses in the quality and quantity of pods and seeds, and severe cases that result in plant mortality. Among these green pea aphids, and in some cases, trips and pod borer are the common important pests against lentil production (Regassa *et al.*, 2006). Weeds, both grass, and broadleaf, are a major impediment to increase lentil production and fast harvesting. From seedling establishment to early flowering stages, lentil is highly susceptible to weed competition. Weeds will drastically reduce lentil yield if left unchecked (Gerba, 2002). In general, lentil production in Ethiopia is influenced by farmers' land holding, agro-ecosystems, biotic and abiotic stresses, insufficient improved crop varieties, seed quality, and integrated nutrient management

Agronomic advancement of lentil in Ethiopia

To characterize agronomic technique, which affects crop production and performance, the terms "Best Management Practices," (Zavattaro *et al.,* 2015) and "Beneficial Management Practices (BMP)" (Baird *et al.,* 2016) have been used extensively. The first term shows how BMPs affect plant growth and maturity, crop production, quality, and efficiency of input, and the latter demonstrate how cropping practices are beneficial for non-cultivation issues. The lentil is one of Ethiopia's largest highlands, which is rotating on thick black soils (Vertisols) with tef, wheat, and barley (Geletu, 2006). In order to enhance and sustain lentil productivity at desired levels for better food and nutritional security, the development and refinement of low–cost lentil production technologies need greater emphasis so that these technologies are acceptable to resource-constrained Ethiopians farmers. Among the most potential technologies in lentil production include improved crop establishment and management practices, integrated soil fertility, and pest management practices, etc. which enhance not only productivity and profitability but also warrant environmental and social sustainability besides nutritional security. Agricultural activities should be economically feasible, ecologically sound, and socially acceptable together with food safety and quality dimensions. In this review, we use both BMP terms to describe key cultivation practices of lentils and highlight those that affect lentil production in Ethiopian.

Seedbed preparation

In the northeast and central Ethiopia, where lentil growing fields on Vertisols remain waterlogged during the main rainy season (June to

August), therefore, adequate provision of surface drainage is very important in land preparation. Preparation of land for lentil starts from May to July using traditional *Maresha* three or four times (Milliom, 1994). The bulk of lentil is mostly grown in Vertisols, where the main rainy season contains excess water. Since lentil is highly sensitive to waterlogging, farmers generally tend to cultivate lentil in on black soils having gentle slope and drain the excess water with ridge and furrow drainage systems (Geletu and Million, 1996). Studies conducted during the last several years have demonstrated the importance of improving drainage on lentil production. According to Tekalign (1992) report, pooled mean grain yield from the broad bed and furrow planting at two locations had an acceptable economic advantage over ridge and furrows planting, with a marginal rate of return of 1125%. Moreover, the broad bed and furrow method was more effective in draining excess water than the farmers' ridge and furrows method at Akaki, Dibandiba, and Keteba, which contributed 59, 102, and 99% for yield improvement, respectively (Figure,2). Likewise, Erkossa *et al*. (2006) reported that the lentil grain yield was significantly increased by 59% under large bed and furrow in comparison to control at the Chef Dona site (from 1029 to 1632 kg ha^{-1}).

More recently, Tolesa & Asrat (2019) observed that raised seedbed type sowing recorded significantly higher lentil yields and protect disease over other seedbed types at the Chefe Donsa site. Thus, drainage management is very important in the effort to boost the productivity of lentils per unit area of land. However, such practice requires strong effort to implement; as a result, farmers are becoming skeptical and reluctant to use these technologies for lentil production. Due to this productivity of lentils is highly hampered by the inherent properties of the soil. Thus, to increase lentil production to achieve food security in this region, more agricultural extension services, and future research should therefore concentrate in particular on the viability and drainage status of the Vertisols.

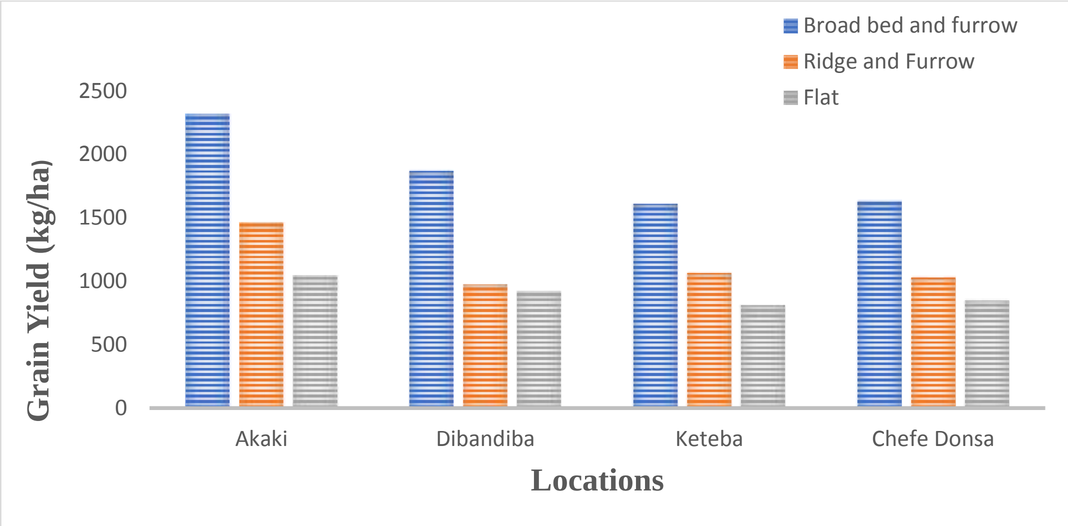


Fig 2. Seed yields of lentils as affected by drainage systems at four locations Source: DZARC, 1991 and Teklu *et al.*, 2006.

Planting method

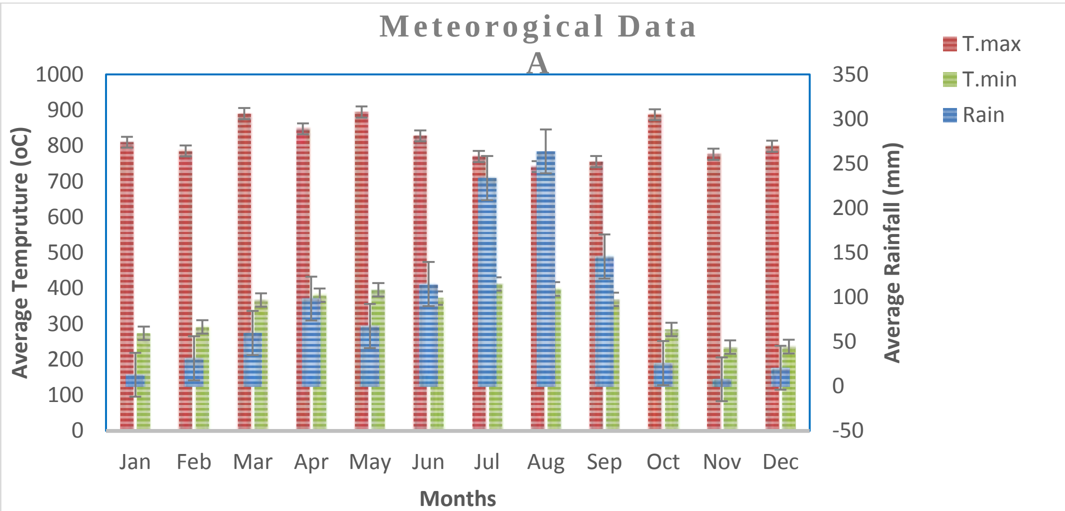
The most widely used sowing method of lentil in Ethiopia is broadcasting. However, recently row planting by drilling method has been also started in some areas. The drilling method has an advantage over the broadcasting method, as it requires less seed, and facilitates mechanical weed control, rouging, and field inspection as well as giving better seed yield. The recommended lentil planting space using the drill method is 20 cm between rows and 2.5 to 5 cm between plants. Generally, the sowing method is an important factor that has a direct effect on seed requirement, plant establishment, and cultural operations, and efficiency of production inputs (Mitiku, 2016).

Sowing Window

Seed development, phenological efficiency, insect-pest, weed dynamics, and crop productivity are all influenced by the time before planting. The environmental situations, topography, and elevation of the area, specific crop/lentil cultivar, soil types, etc. significantly changes with the time of sowing (Pooniya *et al.*, 2015). The choice of an optimal planting time can also compromise between the maximization of yield potential and minimization of the disease level. Early sowing of lentil may not result in higher yields, despite earlier flowering, due to the increased risk of disease and the impact of low temperatures on flowering but later sown can compensate through shortening their vegetative phase and flowering at temperatures more conducive to subsequent pod development (Ali *et al.*, 1998).

In Ethiopia, lentil planting varies across growing regions due to various agroclimatic conditions and cropping systems. Rains of the main growing season always begin in June, and in July and August, the majority of the highlands are rained as low as possible. However, its amount and distribution significantly decline by a head of mid-August (Fig. 9a). Several studies have shown that planting time is among the most important factors in Ethiopia that affect lentil production in many lentil growing areas. It is more serious in low rainfall areas where it fluctuates from season to season... The first experiment was conducted in the late 1970s and early 1980s at several sites of DZARC and other center of the Institute of Agricultural Research. The study conducted at Welenkomi using six sowing dates and two lentil cultivars (small- and large-seeded) indicated that the second fortnight of August was found best for planting lentils (IAR, 1976). Later on, research at Kulumsa revealed that plantation in mid-July was the best time for rising Lentils (DZARC, 1977- 82). In comparison, planting at the DZARC station at the end of June to the beginning of July was higher than the late planting. Similarly, lentil planted at Akaki from late June to mid-July, Ejere from late June to early July, and Chefe Donsa for the second half of July were the best times for small and big crops (DZARC,1977-82). DZARC (1983) annual report showed that early July to mid-August planting was optimum for planting the local and exotic lentil at Tefki and Enwari. (Bejiga, 1991) also stated that the sowing date between the last week of June and the second week of July maximizes lentil yield. Million and Geletu (1998), on the other hand, found that the optimal date for sowing of the early maturing lentil varieties was until mid-July. In the same way, lentil sowing in July has been seen to have a profit over the conventional farmers planting time (late August to September sowing). The study conducted at Mehal-Meda showed that the lentil planted on BBF gave a 158 percent yield gain in early July compared to those on BBF in early August (ShARC, 2002).

Recently, Regassa *et al*. (2006) reported that lentil should be planted from July to mid-August on sloppy fields, but on flooded fields, better started in early September. In double cropping system at Dabat lentil planted in September after harvesting of barley, wheat and tef. It also proposed that in some areas of Bale and the East and West Hararghe areas a small portion of lentil has grown during the short rainy season (April-May). This result also suggested that the late maturing variety Alemaya had responded to a wider sowing date starting from July 19 until the end of August, but to escape the excess rainfall at early stages and the late coming frost on early planting (July 30 to August 09) found to be optimum. Figure 2bclearly stated that the first and the second weeks of August sowing dates were gave higher lentil yields than the third and fourth week of August sowing dates. This yield reduction in late-sown lentils was attributed to moisture stress at flowering and pod-filling stages due to the declined amount of rainfall. However, early-sown in the first three consecutive weeks of July were not suitable for lentil grain yield. This might be early-sown lentils had luxurious vegetative growth accompanied by severe lodging and create favorable conditions for disease and pests due to the prolonged rainfall beyond the normal growing season. From the most obsolete studies above, it is clear that most authors were unable to justify the change in sowing date for the targeted area considering or incorporating physical-chemical characteristics of the soil and the trend rainfall.



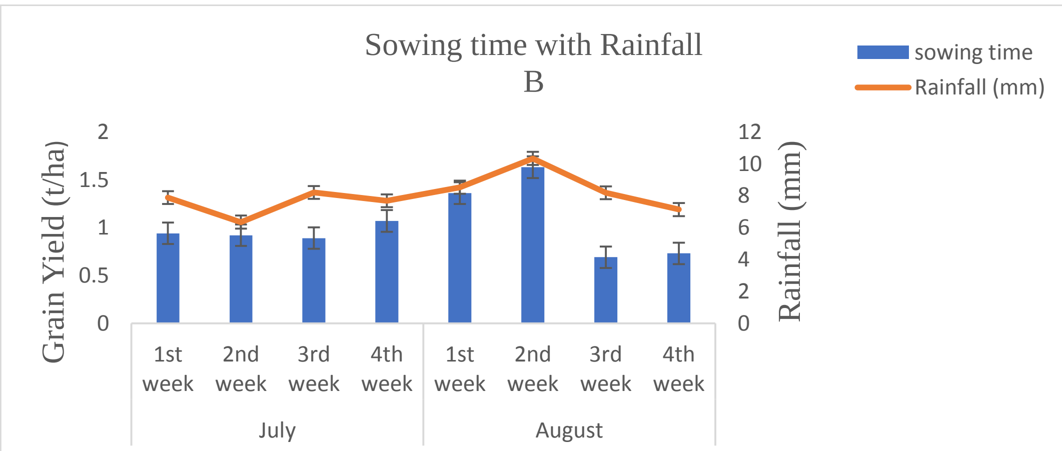


Fig. 9. A thirty-six (1984– 2019) average monthly rainfall pattern of the main lentil research station at Debre Zeit, Ethiopia, during lentil growing season. b Mean grain yield (t ha^{-1}) of lentil genotypes planted on different sowing dates (pooled into weeks) on experimental field conditions in Ethiopia. The data were extracted from results of different field trials conducted over the past several years (1977–2018) mainly on *Vertisols* testing sites (Debre Zeit, Akaki, Chefe Donsa, Inewari, Tefki, Ejeri, and Ginchi) representing the central highland Vertisols lentil growing areas.

Planting density

The number of seeds needed depends on the cropping system, the type of crop variety, the growing season, the test weight, and the seed material's germination percentage. The seed rate is also influenced by environmental conditions and the length of the crop's growth cycle. The seed/seedling rate is determined primarily by the target plant population per unit area (Prasad, 2012). A target plant stand of 130 plants is the suggested plant population for lentil per square meter. The seed rate is determined by the weight of 1000 kernels of each variety and can differ greatly based on the variety and the survival estimate (Fleury & Ag, 2016). In Ethiopia, lentil seed rates, such as those of sowing dates have been conducted at various DZARC and EIAR sites in the late 1970s and early and mid-1980s. The study conducted at Kulumsa showed that the maximum seed yield of lentil was obtained .from the middle two seeding rates (50-55 kg ha^{-1}) Similarly, at Debre Zeit and Chefe Donsa sites, the highest seed yields of lentil were obtained from 70 and 75 kg ha^{-1} seed rate , respectively (DZARC 1977- 82). In parallel tests, 70 kg seed $ha^{-1}$of lentil was beneficial at Akaki's compared to other seed rate. Based on these findings, a seed rate between 50 and 65 kg ha^{-1} was found to be ideal for large lentil cultivars for broadcasting lentil seeding and 65-75 kg ha^{-1} for small seed cultivars (Million and Benwal, 1988). Mitiku (2016) recommended a seed rates for the small lentil 50-65 kg ha^{-1}; for the medium 65-80 kg ha^{-1}, and the heavy or large seed lentil up to 120 kg ha^{-1}. However, the growing environmental and soil types may not be considered in these guidelines. Besides, the seed rate of lentils must also take into account the germination percentage of the seed, the growth habit of a particular cultivar, and, above all, the soil moisture balance and the disease load on the soil, to achieve the optimal plant density to optimize yield and ensure official exploitation of resources. In general, the model-based forecasts of interactions between genotype, climate, and cropping mechanism cannot be taken into account in all recommendations. Therefore, revisit of the seed rate of lentil is an important agronomic practice to rising of lentil productivity in the future.

Fertilizer management on lentil

The Ethiopian Vertisols areas are characterized by smallholder mixed grain farms with a distinct orientation towards livelihoods (Kebede, 2020). The region characterized as big crop production is carried out and high inputs such as DAP and Urea are used, in particular for cereals crop. Legumes are also considered as a secondary crop next to cereals and used in the following cereal crops to maintain soil fertility. According to Berhanu (1985), the pH of 61% of vertisols is 5.5-6.7, 70% of the available P is below 5 ppm and the overall total N content varies from 0.08 to 0.22 percent, which is low. Most growers, however, do not use inorganic fertilizers, since they assume that legumes require no fertilizer and prioritize their application on other crops such as tef and wheat. However, the latest studies of national soil analysis showed that in most parts of Ethiopian highlands, the vast majority of agricultural soils showed low fertility (EthioSIS, 2014). Even if the above-mentioned facts are controversial, good crop production is a well-balanced supply of nutrients in appropriate quantities and forms. Fertilizer management ensures that an adequate fertilizer loss minimization approach allows for good nutrient use to improve crop production and sustain soil fertility at the right time (Dass *et al.,* 2014).

Response of lentil to N application

Like other legumes, lentil requires less nitrogen, since it can biologically fix atmosphere N through Rhizobial bacteria. Under good conditions for the symbiotic association, 70–90% of the N requirement for the lentil crop can be met through biological N fixation, with the remainder derived from soil N sources. Therefore, the application of inorganic N fertilizer would not necessarily react to a well-nodulated lentil culture inoculated with a proper lentil Rhizobium. On the other hand, if lentil is grown in low organic soils, dry environments, or seeded early into cool, wet soils may benefit from the application of low rates of N as a 'starter N' source. However, given that high inorganic N levels are known to have adverse effects on early nodulation, or that they prolong nodulation and lead to poor seedling development, the start N application rate should only be 10–25 kg ha^{-1}. Starter N rates higher than these rates can promote excessive vegetative growth and prolong maturity, both of which lead to poor seed set. In wet conditions, too much vegetative growth may create a microclimate suited for disease development. Research on the use of starter nitrogen has generally found advantages in greenhouse experiments but no or little advantage in the field (Togay *et al.,* 2008). Studies at Ginchi and Dembi in Ethiopia have shown that no apparent difference in lentil production was achieved in the application of N fertilizer in Dembi and the linear output was increased in Ginchi with increased N fertilization (Angaw and Desta, 1990). This may be because of high N soil availability. This research is therefore quite outdated and inadequate to widespread the effect of N applications on the production of lentil grain and in particular its nutrient requirements for vertisols. Most recent study at Northern Ethiopia also showed a non-significant effect of different level of N fertilizer on lentil yield. However, application of starter N at a rate of 20 kg/ha increased lentil yield 100% over nil application (Mesfin et al., 2020). In agreement to this finding a research conducted in USA under rain-fed revealed that application of an external N did not contribute to the yield enhancement of lentil (Huang et al., 2016). Therefore, by considering the diverse agro-ecologies, current soil fertility status and climate variability, the recommendation on N reaction to lentils should be revised, to narrow the large yield gaps that exist between the real and achievable level for food security in the country.

Response of lentil to P application

Since lentils are effective N fixers under most conditions, P may be the most common nutrient limiting lentil growth and yield. To ensure optimum N fastening, optimum seed yield, and time for a harvest, adequate P-nutrition is necessary for lentil production. Phosphorus enhances root development and improves the ability of a lentil crop to tolerate stresses such as drought and frost. In Ethiopia, the first P fertilizer study lentil was conducted using three rates (45, 90, and 135 kg P_2O_5 $ha^{-1}$and two sources (TSP and DAP) at Debre Zeit station, the result indicated that neither the rates nor the sources showed marked differences for seed yield. Although neither supported nor confirmed by the research results, the use of 100 kg ha^{-1} of DAP has been recommended as optimum for lentils (DZARC 1977-82). Similarly, Angaw and Desta (1990) reported that lentils showed no response to P applications at Debre Zeit and Akaki. Angaw and Asnakew (1993) also found that there was no apparent lentil yield difference with P fertilizer application at Dembi and Ginchi sites. This might be the response of P fertilizer application are related to environmental factors, with the greatest responses typically occurring in cool-wet soils. While lentil has a relatively high demand for P, the response of seeds to the application of P fertilizer is inconsistent, even in soils of low soil P. Moreover, Ethiopian Vertisols have high P-fixing properties due to continuously cultivation as a result of a shortage of land (Hailu, 1991). This indicating that there is a high chance of getting a lack of crop response to P application. Thus, many investigators failed to find a positive response to P applied.

However, recent fertilizer studies indicated that lentil is significantly responsive to P application. A fertilizer study conducted at West Showa Vertisols sites indicated that the application of 20 kg P ha^{-1}, gave comparable grain yield and had a 64% yield advantage over unfertilized (Zike *et al*., 2017). Similarly, Gebrekidan *et al. (*2020) reported that combined application of 20/20 kg P/S ha-1 markedly improved the grain yield of lentil by 83% over the control at Debre Zeit on-farm field study. In comparison, Tesfahun (2007), the P rate of increase of up to 30 kg ha^{-1} in Haramay University Station, has found significant benefits in terms of seed return. Furthermore, lentil seed is extremely sensitive to the seed -row appliedto P fertilizer and the plant stand and seed yield can be substantially reduced at higher P levels. Small amounts of P 20 kg ha^{-1} based on a narrow seed row at 15–20 cm spacing) placed with the seed may not be harmful and the adverse effect on plant stands may be more severe under drier soil conditions. Where P fertilizer application is necessary, banding the fertilizer to the side away from the seed is recommended. Overall, since the soil in the highlands of Ethiopia varies from farms to valleys and hillsides, crop output also varies and agronomic recommendations shift from appropriate to inappropriate. Therefore, P fertilizer application studies on lentils in Ethiopia have been further verified by considering soil type, soil depth, and the soil/crop/input histories of the farmers' fields, and the economic feasibility of fertilizer for small-scale farmers.

Response of lentil to S application

Unlike NPK fertilizer, sulfur is important for lentil production, but due to the long-term application of high input from DAP and Urea fertilizer, intensive cropping, high-yielding cultivars which extract higher S levels from soils have caused large nutrient deficits, including S (Kissi, 2014). Additionally, lentil being a leguminous crop, the requirement of N fulfill mainly from symbiotic N_2 fixation, which may be affected by S scarcity. Previously, there was no documented recommendation of S fertilizer for lentil production in Ethiopia. Recently, the use of 40 kg S ha^{-1}greatly increased the grain yield of lentil, but this was not statistically higher than 20 kg S ha^{-1} in the main rainfed conditions (Gebrekidan *et al.*, 2019). Gebrekidan *et al*. (2020) found that the combined application of S and P gave the highest grain yield, and hence, 20 kg ha^{-1}S and P were recommended for the study areas and other lentil production areas having similar agroecology. In general, the response of lentil to S application in most lentil growing areas is not well studied and its economic benefits are not yet determined. In the future, neglecting this fertilizer may be aggravated unless attention is given to reverse it. Besides, organic fertilizers such as farmyard manure (FYM) as the main source of soil nutrients by most Ethiopian smallholder farmers. However, the response of lentils to organic fertilizers and micronutrients application as well as the combined study of organic and inorganic fertilizer has not yet reported.

Rhizobium inoculation

In legumes, root nodules are highly specialized structures formed as a result of interactions between the host plant and the invading Rhizobium. The symbiosis between legume and rhizobia contributes to the BNF phase which can most much entirely satisfy the plant's N requirements (Santos *et al.,* 2019). Like other annual legumes, while inoculating seeds, lentils may provide a proportion of their N requirements through means of symbiotic N_2 fixation. FAOSTAT (2004) data showed that the annual nitrogen fixation by lentils was about 73 kg N $ha^{-1}yr^{-1}$ by the above-ground plant part or110 kg N $ha^{-1}yr^{-1}$ including the below-ground parts. The average removal of nitrogen by lentil was approximately 65 kg N $ha^{-1}yr^{-1}$ in the harvested grain and lentil stored 8 kg N $ha^{-1}yr^{-1}$ in the soil for the crops (Rashid *et al.,* 2012).

In the past, only a few studies on rhizobiology have been done, with work on the rhizobiology of highland pulses such as Faba bean, chickpea, field pea, and lentil starting in 1982 at Nazret Research Center and moving to Holetta Research Center in 1986. (Tekalign and Asgelil, 1994). Little study has been conducted in Ethiopia about lentil growth and yield effects of Rhizobium inoculation. The first research on the need for Rhizobium inoculation in lentils was conducted at Ginchi and Dembi in 1989. . The result showed that there were no major variations in performance between the treatments (IAR, 1989). Similarly, the findings of a foreign lentil reaction test showed that no major variations were seen between treatments due to the soil fertility status of the areas (IAR, 1991).Recently, Tena *et al.* (2016) found that grain yields of lentil varieties were increased by 59%, 44%, and 40% over the control treatments when inoculated with Lt29, Lt5, and with N fertilizer, respectively under field condition. Likewise, inoculation with lt29, lt87, and lt5 improved grain yields in the pot experiment by 92%, 74%, and 67% over the control respectively. They also conclud that under field conditions, the amount of N fixed from lentil ranges from 16.9 to 31.2 kg ha^{-1}. A study made by Kassa (2018) reported that combined application of 150 kg NPSZnB ha^{-1} and rhizobium inoculation increased grain yield by 46% compared to the control. Gebrekidan *et al.* (2019) also confirmed S fertilization with the strain of Rhizobia inoculation enhances the grain yield of lentils by 8.5% over the control. Reports, therefore, indicated that the use of lentil inoculants favors yields, but BNF cannot fully substitute N-fertilizers, particularly in soils with very low N concentration. Thus, the use of 15 or 20 kg N $ha^{-1}$with sowing inoculation can boost grain output (Soares *et al.,* 2016), but increased sowing doses of N may cause reduced nodulation (Hungria *et al*., 2003).

Though the massive economic and environmental benefits of bio-fertilizers, the use in general has remained weak due to limited options of effective commercial BNF inoculants adaptable to diverse growing conditions and poor supply systems. Besides the infection process could fail due to several reasons including; no or few rhizobia in the soil, inability of the rhizobia to survive in the soil due to intrinsic limitations, inappropriate strains of rhizobia in the soil, efficient rhizobia being out-competed by less efficient/effective soil rhizobia, failure of the plant to invest in the symbiosis either through lack (e.g early in the seedling stage) of time or resources or through altered metabolism (e.g. towards nitrate reduction in soils high in available nitrogen). Many reports have highlighted that the potentials of the native rhizobia population existing in the country is untapped. Therefore, extensive and systematic survey collection programs covering a wide range of lentil-growing agro-ecologies are highly needed to address the current research gaps.

Agronomic interventions for weed management

Weeds are a major constraint for legume production both in private mechanized and labor-intensive smallholder farming systems in Ethiopia. In general, grain legumes are more sensitive to biotic (weed) stresses than other crops and are often confronted with several major constraints simultaneously. Since lentil are sown at the beginning of the rainy season, weeds grow with them, and removing them is necessary. For this constraint, there is usually a research output available for its alleviation, but much of lentil research, and other pulses generally, involves studies on various levels of a single, or at best a few, factors keeping other possible yield-determining factors constant. This traditional, reductionist approach has increased our understanding of the major yield-limiting factors to lentil/pulse production. However, if farmers are to benefit from this component knowledge, it must be integrated into an overall crop management process, accounting for interactions between factors, which include integrated crop management (ICM), and integrated weed management (IWM) have been encouraged. Overall, there is a paucity of agronomic intervention research on lentil weed management in Ethiopia. Nevertheless, few studies shuch as Negussie *et al.* (1993) reported a higher grain yield of lentils with the combinations of conservation tillage, hand weeding, and herbicides application. The result showed that 70% yield increment could be realized through the integrated use of minimum tillage and twice weeding; or zero tillage, terbutryn and supplementary hand weeding. Similarly, the better yield of lentil and lower weed biomass were obtained from the application of herbicides coupled with hand-weeding, indicating better control of the weeds (DZARC, 1996, 1997).

Lentil cropping systems

A wide variety of cropping patterns is followed in different agro-ecological zones of Ethiopia depending on land characteristics and soil moisture regimes. Tef, wheat, maize, barley, and sorghum are the major cereal crops of Ethiopia and are grown extensively throughout the year. Hence, all the major cropping patterns are the above-mentioned crop-based. Lentil is grown as a summer crop largely under rainfed conditions in residual/ conserved moisture. However, in some parts of Ethiopia like Southweast Arsi, South Wollo, and North Shewa Zone, it is also cultivated in belg season.. Depending upon the annual precipitation pattern and demands of the local cropping cycle, lentil is grown to a large extent as a component of rotation with different cereals and to some extent as intercropping with wheat. The inclusion of lentils in various cropping systems benefits the companion crop or succeeding crop by improving the physical and chemical properties of soil as a result of biological nitrogen fixation and other rotational effects. The major lentil-based rotation patterns are tef-lentil, wheat-lentil, and barley-lentil. Studies conducted so far indicated that nutrient status and the balance of nutrients were significantly influenced by the wheat- lentil intercropping system under supplementary irrigation in the semi-arid highland of Tigray. As a result, the levels of soil nitrogen, phosphorus, and intercropping with single wheat have been shown to marginally increase (Etany, 2016). Similarly, Annual research reports of DZARC (2012) proved that intercropping of wheat with various leguminous crops showed significant yield differences among them. Accordingly, grass pea, fenugreek, chickpea, lentil, and clover yielded in a declining amount. Almaz *et al*. (2021) reported that incorporation of lentil in wheat based cropping system at any combination was found to be more profitable and productive compared to sole wheat and lentil. Among crop combinations, 2:1 wheat-lentil intercropping combinations gave the highest LER, ATER, and MAI values compared to 1:1, 1:2 wheat lentil intercropping combinations. However, as compared to other legume, not much cropping system research work has been done on lentil in Ethiopia, therefore, research focus on lentil cropping system should be encourage inorder to assess the opportunities and challenges of lentil cropping system and identify best cropping syetm for an intensification of legume production in Ethiopia agriculture.

Yield improvement of lentil though agronomic intervention: where and how?

In the past, the discovery and implementation of new technology may have coincided with economic factors to create improvements in cropping practices that increased grain yield. While it is generally acknowledged that breeding and agronomic practices have contributed to increased yields, their relative contributions have varied depending on the crop species and the climate (Anderson *et al.,* 2005). In rainfed agriculture, there are two large areas for improving the yield of lentils.

Tactical management

Decisions concerning cultivar preference, sowing date, seed or plant population, fertilizers rates, and application techniques, weed, and pest control methods are considered important to the development of modern crops (Siddique *et al.,* 2012). Their contributions to improved yields have been modified and progressed through variation and crop technology (Ward & Siddique, 2015). Farmers' management decisions in Ethiopia are also influenced by seasonal variations in agronomic activities in rainfed regions, which are mainly related to rainfall. Seasonal variance nearly often has a huge effect on how people respond to tactical management activities. Since lentil is grown mostly in the highland Vertisols of Ethiopia, the crop is usually affected by drainage problems. Thus, some tactical management practices used to reduce the effects of waterlogging in lentil involve sowing time, cultivar selection, seeding rate, and drainage types considering the biochemical and physiological responses for waterlogging tolerance. Future agronomic research can focus on enhancing farmers' ability to adapt tactical management using an agronomic model of cultivar-specific parameters to study and forecast genotype activity in a variety of ecosystems and cropping systems, as well as for a variety of objectives. Model-based predictions of the relationship between genotype, climate, and cropping mechanism are used in three ways:

1) Refining the definition of breeding targets, i.e., identifying the phenological, morphological, and physiological traits to breed for a given aim and environment/cropping system (ideo-typing).
2) Refining the analysis of multi-environment cultivar trials, by characterizing the environments to optimize networks, and understand the interactions between genotype, environment, and cropping systems that are observed in networks (agronomic diagnosis).
3) Helping in the use of new cultivars, by supporting the choice of the best cultivar to grow in a given cropping system, and/or a given environment (cultivar choice).

Strategic management

This mostly focuses on the improvement of the soil, even though decisions about the sequence of crops are also taken before the seed. Improved soil may include strategic activities such as acidity/salinity enhancement, soil compaction, water-logging, non-weathering, and poor SOC stocks, which are also linked to other soil physical deficiencies (Verhulst *et al.*, 2013). Latest remote sensing and global positioning system strategies including yield mapping, variable rate technology, auto-steering, and managed traffic (which can be a blend of tactical and strategic management) have shown promise in lowering manufacturing costs and increasing accuracy (Robertson *et al.*, 2012). On the other hand, components of the conservation agriculture system (zero or minimum tillage, residue retention), using alternative cropping system (crop rotation, intercropping and double cropping), bringing additional area through irrigated and beleg season might also be considered, wholly or partly, as strategic management. Even though the cultivation of lentils recorded a downward trend in most niche areas of lentils in the main season, few lowland areas of Ethiopia have emerged as potential areas of lentil cultivation and expansion. Therefore, searching for additional areas with full agronomic practices is one of the strategic managements to increase lentil production and productivity.

Conclusions and Future Outlooks

The improved agronomic practices and strategies about Ethiopia's lentil production would enhance the capacity of farmers to grow sustainable lentils in Ethiopia despite numerous production vulnerabilities, as discussed in this paper. As a result, an effort has been made in this study to address enhanced lentil production practices that can play a critical role in Ethiopia's long-term lentil production. Which is emphasized nearly all research and development efforts from their inception in the late 1970s to the present, with a focus on aspects of crop management practices that are a bottleneck for lentil productivity in Ethiopia. The paper also stressed that the majority of crop management recommendations for lentil cultivation are outdated and did not reflect the current agro-climatic setup or upcoming environmental changes. Similarly, many recent studies had significant shortcomings in portraying the diversity of emerging agro-ecologies and the dynamism of farming systems. Furthermore, developing a package of modern management practices and upgrading the existing packages would go a long way towards improving Ethiopia's lentil production potential. Thus, reseachers in Ethiopia have developed cutting-edge technology ranging from the varietal growth to crop and resource management practices to improve lentil production. As a result, future research should account for these constraints, and crop management studies should be conducted in a more systematic and organized manner. From this review, the following points reflect the main findings collected with some of the issues requiring immediate attention and others requiring further investigation:

1) In Ethiopia, not much lentil cropping system research have been done compared to other legumes. Therefore, lentil-based cropping systems should be developed for different regions together with information on genotypic compatibility of component crops, spatial arrangements, and fertilizer use.
2) More detailed investigations into the use of bio-fertilizers, inorganic fertilizer, and management practices are needed in lentil cropping systems. It is essential to identify the most successful rhizobia strains under various agro-ecological conditions. There is also further verified that crop-soil management aspects of the Vertisols, particularly agronomic requirements, are not yet adequately addressed, which may need research priority.
3) Improved lentil farm technology and agronomic practices, as well as the promotion and adoption of disease and insect pest resistant high yielding lentil cultivars, are all urgently required in the intensive lentil cropping systems. In addition to their other benefits, bed planting,

planting on ridges, and using resistant cultivars can help with waterlogging prevention.

4) Lentil production has risen dramatically over the last few decades in central parts of Ethiopia. However, maintaining this production trend is a major challenge for researchers, extension agencies, and farmers in these major production areas. Thus, lentil crop must be introduced to non-traditional areas and cereal fallow areas in various agro-ecological zones of the country.

5) Investigation of the physiological aspects of yield variation under different environmental conditions, which might be helpful for agronomic manipulations.

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