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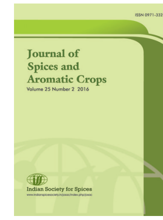

Garlic nutrient management in Ethiopia - a review

G Diriba-Shiferaw

Department of Plant Science/Horticulture,
College of Agriculture & Environmental Sciences,
Arsi University, P.O. Box 193 Asella, Ethiopia.
E-mail: dsphd2010@gmail.com

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Abstract

The main aim of this review is to provide an overview of the garlic crop productivity and its production management requirements like soil, climate and fertilization in general and specifically in Ethiopia, comparing them with current research trends and to indicate future benefits of soil nutrient management investigations. The application of balanced nutrients under optimum moisture availability in different soil types is an important crop management strategy, which may help maximizing crop yield and quality. Also, lack of optimum nutrients and moisture in the soil has been the major bottlenecks of garlic production and productivity; since the crop has a very shallow root system that requires frequent irrigation and fertilization with different types of fertilizers under various soil types. Low soil fertility is one of the principal and pervasive constraints to garlic production in Ethiopia; thus, there are differences among soil types in yielding ability under different nutrients and soil characteristics. Most smallholder farmers in Ethiopia appreciate the value of fertilizers, but they seldom apply them at the recommended rates and at the appropriate time according to the soil characteristics. These are because of high cost, lack of credit, delivery delays, and low and variable returns. In addition, the traditional organic inputs, like crop residues and animal manures, it cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials, and the high labor demands for processing and application. However, it is possible to increase garlic crop yields through identification/selection of soil type and balanced nutrients application or searching for other nutrients sources beyond Urea and Diammonium phosphate especially in Ethiopian condition. Therefore, the integrated use of both the organic and inorganic fertilizers was felt as the best option to increase both yield potential and quality of garlic crop.

Keywords: bulb crops, garlic productivity, nutrients, organic and inorganic fertilizers, soil and climate requirements, soil types, yield and quality

Introduction

Garlic is one of the main *Allium* vegetable crops known worldwide. The genus *Allium*, which belongs to the family Alliaceae, is diverse and comprises about 750 species; but only seven of them are widely cultivated in different parts of the world. Of these, important in Ethiopia are onion (*Allium cepa* L.), shallot (*Allium cepa* var. *ascalonicum* L.), garlic (*Allium sativum* L.) and leek (*Allium ampeloprasum* L.). The first three are diploid with the basic chromosome number of 2n=16 whereas leek is teteraploid with 2n=32 (Jones 1990; Currah & Rabinowitch 2002). It is one of the oldest cultivated vegetables and the second most widely produced *Allium* next to onion (Hamma *et al.* 2013; Hassan 2015). Garlic is used as a seasoning in many foods worldwide; without garlic, many of our popular dishes would lack the flavor and character that make them favorites. Garlic's volatile oil has many sulphur containing compounds that are responsible for the strong odor, its distinctive flavor and pungency as well as for its healthful benefits (Salomon 2002). Moreover, it contains considerable amounts of minerals like Ca, P and K, and its leaves are sources of protein, vitamin A and C (Maly *et al*. 1998). Garlic has higher nutritive value than other bulb crops: 30–35% dry matter, 6–7% protein, 0.2% lipid, 23–28% carbohydrate, 0.7–0.9% fiber, 1.1–1.4% ash matter and vitamins, especially B_1, B_2, B_6 and C. Garlic also contains antibiotics *garlicin* and *allistatin*, a number of enzymes, amino acids, universal substances, including trace elements (Maly *et al*. 1998). Economic significance of garlic in Ethiopia is quite considerable; it is grown as spice and used for flavouring local dishes, and contributes to the national economy as export commodity (Fekadu & Dandena 2006). Production of cash crops like garlic and other spices is proved to be income generating activity for farmers, especially for those who have limited cultivated land or small holder farmers (FAO 2006).

In Ethiopia, small growers in the highlands grow garlic traditionally but due to obsolete cultural practices, yields are generally low (ENAIA 2003). Diverse crop management problems and the nature of propagation accounted for the low yield of garlic in Ethiopia; major production constraints include lack of proper planting material (improved varieties), inappropriate agronomic practices, absence of proper pest and disease management practices and marketing facilities, and lower soil fertility status in many soil types particularly N and P nutrients (Getachew & Asfaw 2000).

Area and production

Garlic has a wide area of adaptation and cultivation throughout the world. On a global scale, leading producers are China, India, Korea, Egypt, Thailand and Spain. Majority of the garlic is produced in Asia (87%), China and India, being the largest producers, collectively accounting for 78% of the production but in Africa accounting only 2.8% of the total world production. However, the yield produced in China (23.08 t ha^{-1}) was more than four times higher than the yield observed in India (5.27 t ha^{-1}) and higher than the world mean (16.71 t ha^{-1}) (FAOSTAT 2011). World area coverage by garlic was increased from 1,142,220 ha in 2003 to 1,422,408 ha in 2011 with an average productivity of 12.0 and 16.71 t ha^{-1}, respectively (FAO 2003a; FAOSTAT 2011). In Ethiopia, garlic is one of the important bulb crops produced for home consumption and is a sources of income to many peasant farmers in many parts of the country (Metasebia & Shimelis 1998; Getachew & Asfaw 2000). Garlic area was increased from 6,042 ha in 2001/02 to 21,258 ha of land in 2012/13 with a total production increment from 79,421 to 222,548 tonnes of bulbs, but its productivity was decreased from 13.20 and 10.47 t ha^{-1}, respectively (CACC 2002; CSA 2013). The yield differences exhibited by the Ethiopia from the developed countries most likely reflect differences in technological resources and aspects related to the management of the crop, rather than to differences in genetic background and performance of the cultivars used. The bulk of garlic for domestic market is produced in homestead gardens of subsistence farmers especially in Ambo, Debrework, Adiet, Sinnana and many other areas of Ethiopian highlands, and characterized by low yields of about 11.7 t ha^{-1} (CSA 2010) and in East shows about 11.31 t ha^{-1} (CSA 2013). Out of the total production, greater than 58% was used for household consumption, 24.5% for market and 16% for seed. In this country, garlic is used as ingredient of local stew 'wot' and for formulation of local medicines (CSA 2010).

Of the total production of Alliums in the country, Ethiopia, the area coverage of garlic in 2007/2008 was 9,316.90 ha, and total production was about 103,541.68 tonnes of bulbs, which was produced by 1,490,681 landholders (CSA 2008). Garlic accounts for 0.06% of area and 0.62% of yield from the total private peasant holdings of 'Meher' season temporary crops in the country. In 2009/2010, CSA (2010) reported that national garlic cultivated land was 15,361 ha owned by 2.079 million landholders. Among vegetable crops it ranks second in the number of landholders next to Ethiopian cabbage (2.799 million landholders). Garlic is produced mainly in the mid and high lands of the country (Getachew & Asfaw 2000; CACC 2002).

Climate and soil

Garlic is the most widely cultivated *Allium* species in Ethiopia and it has a wide range of climatic and soil adaptation. Climatically, regions with a reasonably mild winter with some rainfall followed by a sunny dry summer, which is good for maturity and harvesting the bulbs, are ideal for garlic production (Lemma & Herath 1994). Rubatzky & Yamaguchi (1997) indicated that garlic plants are very hardy and tolerate low, even some freezing temperatures, although in some areas of extreme cold it may not survive the winter. Garlic production occurs in most countries ranging from the equator to about the 50^{o} latitude and grows best within the range of 12-24^{o}C temperature. High temperatures are required for bulb development, but cooler conditions in the early stages favor vegetative growth and elevations from 500-2000 meters above sea level provide suitable growth condition (Rice *et al*. 1990). Excessive humidity and rainfall are detrimental to the vegetative growth and bulb formation. Insufficient moisture and water logging easily stress plants. So, to attain maximum yield, moisture in the top 30 cm of soil should be maintained close to field capacity for growth (Rubatzky & Yamaguchi 1997).

The seasonal and annual variations in rainfall severely impede agricultural productivity in general and garlic production in particular. Even though, irrigation is available in all areas, it requires a huge financial and capital investment; as a result, rain fed agriculture may continue to play a major role in the near future, especially in areas with sufficient rainfall. Bulb crops require a supplemental irrigation where rainfall is insufficient (Tilahun *et al*. 2011). Garlic is a high-value crop, which requires rich soil, good drainage, friable soil-preferably with high organic matter content, and water should not be deficient during bulb formation until two weeks before harvesting time. Excess supply of water two weeks before harvesting time affects the storage quality and the crop prefers a soil with a pH of 6.5-7.5 as it is sensitive to higher acidity (Bachmann 2001; Potgieter 2006). The most suitable soil types for garlic crop growth are sandy loam to sandy clay loam, and very fine sandy loam (silts) soils, deep mineral topsoil, well drained muck soils and relatively high (greater than 2.0%) in organic matter are ideally suited for growing bulb. The crop produces a coarse rooting system, whilst requiring a degree of firmness for good root to soil contact; the soil must be free from compaction and well drained. Under poor soil drainage, bulbs become discolored and under clay loam soil conditions, the bulbs are deformed and difficult to harvest.

From the various soil types found in Ethiopia, Cambisols (12%), Vertisols (9%), Fluvisols (7%), Nitosols (6%) and Andosols (1%) are the most important agricultural soils (FAO 1986). The two soil types found in Debre Zeit area are Andosols and Vertisols with an organic matter content of about 2.05% and 1.89%, respectively (M'Nen 1992). Andosols (light gray soil) have well-drained properties, relatively higher organic matter, and nutrients (N, K and some micronutrients) content as compared to Vertisols. The higher sand content of Andosols is more important for bulb growth and easily expansion in the soil, but it has a characteristic of fixing nutrients particularly P, which led to unavailability of the nutrient for the crop (Wakene *et al*. 2002). According to M'Nen (1992), Vertisols are highly productive in the area; however, drainage and management of the soil is cumbersome. Covering about 8 million ha in the highlands, Vertisols are considered suitable for cereals, pulses as well as for vegetables. However, their low N supply capacity and meager organic matter content coupled with their severe water logging problems limit their productivity (Teklu & Teklewold 2009). The crop requires thoroughly prepared soil seedbed by repeated ploughing and light irrigation before planting the crop with a well-decomposed FYM application at the rate of 10 to 20 t ha^{-1} (FAO 2003b). Soils with high organic matter content are preferred due to their increased moisture and nutrient-holding capacity, and less proneness to crusting and compaction (Bodnar *et al*. 1998). The application of organic fertilizers assist structuring of clay soil to open and admit air penetration to roots and drainage, both conditions necessary for satisfactory plant growth (Eimhoit *et al*. 2005).

Nutrient requirements

Fertilizer requirements of garlic crop vary with fertility status of the soil, availability of soil moisture, variety of the crop, purpose for which the crop is grown, etc. Of many factors, fertility status of the soils significantly affecting garlic crop yield. The three major essential plant nutrients, N, P and K are increasingly in short supply in the soils of many African countries because of the large quantities taken up from the soil relative to the other essential nutrients (Marschner 1995; Rao *et al.* 1998), which is true also for many Ethiopian soils (Yohannes 1994). Soil fertility studies conducted at different locations in Ethiopia for different crops have shown significant yield responses to applied N and P fertilizers, indicating that most of the Ethiopian soils are deficient in nutrients, especially N and P (Berga *et al.* 1994; Yohannes 1994).

Bulb crops are high value crops and their improved yield and quality are important economic considerations and they are more susceptible than most crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence, they require and often respond well to additional fertilizers (Brewster 1994). Garlic has a moderate to high fertilizer requirement, depending on the nutrient status of the soil (Berga *et al*. 1994).

Today, efforts to obtain higher yields of garlic have led to the application of various types of fertilizers. The different types of fertilizers have dissimilar concentrations of plant nutrients and therefore affect the soil environment differently. As humankind strives to obtain higher yields of garlic through heavy application of fertilizers, such procedures must equally preserve the quality of the crop (Cantwell *et al*. 2006). Bulb crops are a heavy feeder, requiring ample supplies of N, P, and K in either the form of inorganic or organic fertilizers or a combination of them. Sub-optimal levels of these nutrients in the soil adversely affect the yield, quality and storability of bulbs (Gubb & Tavis 2002).

Mineral fertilizers in garlic production

Nitrogen (N) is a vitally important raw material required for the growth of plants, as it is an essential constituent of metabolically active compounds such as amino acids, proteins, enzymes, coenzymes and some non-proteinous compounds. On the other hand, extensive use of N-based fertilizers worldwide has resulted insignificant environmental problems associated with high-input agricultural production systems. The pollution of natural resources and rising costs of N fertilizers has also focused greater attention to improve their use in agriculture and created the development of improved N use efficient crop plants (Vitousek *et al*. 1997; Raun & Johnson 1999; Good *et al*. 2004).

On the other hand, smallholder farmers in Ethiopia are known to use low rates of inorganic N and P fertilizers (less than 100 kg ha^{-1} of urea and/or DAP) for crop production due to prohibitively high prices (Morris *et al*. 2007; Demere & Gebrekidan 2008; Tesfaye *et al*. 2011). The low application of inorganic fertilizers to crops may stem from reluctance of farmers to apply fertilizers due to anticipated low response of the crop because of climatic uncertainty (particularly erratic rainfall) during the main growing season (Morris *et al*. 2007). It may also be attributed to lack of knowledge as to which kinds and rates of fertilizers are recommended for their specific crops, soils, and agro-climatic conditions; or to existence of disparities in access to fertilizers or purchasing power among farmers as a result of varied resource endowments (Murage *et al*. 2000; Morris *et al*. 2007). Farmers apply also low amounts of organic fertilizers owing to competing needs such as the use of cow dung as a source of energy for cooking and crop residues as feed for animals (Morris *et al*. 2007).

The total amount of N required for crops will vary with the soil type, the previous crop grown, and the amount of organic matter present in the soil and the climatic conditions during the growing season. Kakar *et al*. (2002) reported that N accounts for a higher percentage of the variation in plant height, leaf area, leaf count, and fresh and dry plant mass when it was increased from 50 to 200 kg ha^{-1}. Garlic will generally require 70-125 kg N ha^{-1} and one-half of it should be applied as soon as the crop begins to grow; the remainder should be split into two to three applications at three-week intervals and should be completed within 4-6 weeks in the California, USA (Bodnar *et al*. 1998). The production of vigorous sprouts is one of the most important factors of successful garlic production (Potgieter 2006). Adequate application of N during sprouting stage and application of different sources and rates of N play an important role in the production of vigorous vegetative and optimum leaf expansion of crops and influences bulb size produced (Stork *et al*. 2004). Excessive application of N at a late vegetative stage of garlic crop can limit yields and increases storage losses, while inadequate N can hasten maturity and limit yield (Batal *et al*. 1994). It is best not to apply N when the bulbs are beginning to enlarge since it will encourage excessive leaf growth and reduce bulb size (Bachmann 2001).

N and P are among the most important and frequently applied nutrients as mineral fertilizers for producing most crops in Ethiopia. However, the rates of application of the nutrients are far less than the requirements and based on blanket recommendations on different areas and soils (Fikreyohannes 2005). However, the crop nutrient requirements vary with species, variety, soil type and season, a blanket recommendation of 92 kg ha^{-1} N and P_2O_5 each of N and P fertilizer are in using for garlic production in many areas of Ethiopia (Yohannes 1994). Kilgori *et al*. (2007) reported similarly a significantly increased cured bulb yield of garlic with increased N from 0 to 60 and 120 kg ha^{-1}. However, they found that higher dosage of 180 and 240 kg N ha^{-1} reduced the bulb yield.

P deficiency is one of the largest constraints to crop production in many tropical soils, owing to low native contents and high P fixation capacity of the soil (Norman *et al*. 1995; Fairhust *et al*. 1999). Phosphorus is essential for root development and when the availability is limited, the growth of plant can be reduced. It is involved in several physiological and biochemical processes in plant maturity, fruit setting and seed production (Miller & Donanue 1995). It is part of plant nucleoprotein and hence important in plant heredity and also plays a role in cell division, stimulates root growth, and hastens plant maturity and physiologically notable in the storage and transfer bonds of ATP. The need for P is critical during the early stage of growth when normal meristem development and rapid height growth are necessary for a high yield. The movement of P in soils is very low and its uptake generally depends on the concentration gradient and diffusion in the soil near roots (McPharlin & Robertson 1999).

In onions, P deficiencies reduce root and leaf growth, bulb size and yield and can delay maturation (Greenwood *et al*. 2001). In soils that are moderately low in P, garlic growth and yield can be enhanced by applied P. Results of long-term fertilizer trials on loamy sand soils in Germany have shown a strong response of onions to P fertilization in the range 0-52 kg P ha^{-1} (Alt *et al*. 1999). Depending on yield levels, P uptake rates in onion estimated to be about 15-30 kg ha^{-1} (Pire *et al*. 2001; Salo *et al*. 2002). In western Kenya, as reported by Jamma (1998) soil, water and nutrient losses tremendously reduced by P addition because of the rapid formation of soil cover. Application of P from 29 to 48 kg P ha^{-1} can usually be adequate for better garlic production while in the desert areas, however, rates of P up to 96 kg P ha^{-1} may be needed (Sims *et al*. 2003).

Vegetable production could be highly profitable, if the correct amount and type of fertilizer is applied and the crop species grown utilizes the fertilizer nutrients very efficiently (Anonymous 2002). Application of P fertilizers generally has a great impact on crop yields because P deficiency limits the response of plants to other nutrients, especially on highly weathered and leached soils of both tropical and temperate regions of the world where soil acidity causes infertility and general limitation to crop production (Alaam *et al*. 2002). Beside P fertilizer management, soil type could significantly determine the efficiency of P use by specific crop species (Ezekiel & Adigun 2005).

Best quality garlic can be produced through application of balanced fertilizers (Cantwell *et al*. 2006). Research work has been done on the base of NP in different soil types (Brewster 1994; Lemma & Herath 1994) and in various climatic conditions, but very limited work has been reported on various sources of fertilizers for a certain nutrient. Among the major macronutrients, potassium (K) and sulphur (S) have been ignored by most of our local growers to apply to their crops (Berga *et al*. 1994; Yohannes 1994). Though the quantity of K and S in most of the soils is adequate, there is also evidence of fixation of K and leaching of S in different types of soils (Murashkina *et al*. 2006). Therefore, the application of K and S to soils having even medium amounts of K and S contents may still show positive effects on plants (Potgieter 2006). In addition, balanced application of nutrients can improve soil fertility and eliminate the effect of nutrient deficiencies beyond improving of garlic productivity and quality (Lujiu *et al*. 2004). Similarly, garlic growth, nutrients concentration and uptake by the crop, quality and postharvest shelf-life of garlic bulbs were significantly increased with integrated fertilization of the crop using different nutrients/elements (Diriba-Shiferaw *et al*. 2013a, 2013b; 2014).

Mineral fertilizers of balanced doses increased the leaf area, photosynthetic productivity, yield of garlic plant in particular, and resulted in substantial increases in crop production in general (Zhou *et al*. 2005). They investigated that fertilization of the soils in 12 trials on garlic and other vegetables with NPK, adding 60-120 kg S ha^{-1}, increased yields by 16.0-36.4% and high vegetable quality and in nutrient management, S combined with other nutrients has to become a common fertilizer practice to guarantee optimal crop production as also reported by Shalini *et al*. (2002). The study undertaken on two soils types by Diriba-Shiferaw *et al*. (2015) also showed that the growth, yield and economic potential of garlic were increased in response to the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} with a benefit cost ratio of 6.44:1 on Andosols and 138 kg N + 40 kg P + 60 kg S ha^{-1} with a benefit cost ratio of 5.86:1 on Vertisols. However, they concluded that application of 92 kg N + 40 kg P + 30 kg S ha^{-1} combination along with 140 kg ha^{-1} KCl fertilizer on both soils are optimum and economical to attain better productivity of garlic crop to enhance household income and livelihoods of the farmers in the study areas.

Onions take up K in quantities nearly equivalent to N (Pire *et al*. 2001; Singh & Verma 2001; Salo *et al*. 2002). Moreover, like N, K is easily leached from soils and fertilization may be needed for high yields (Marschner 1995). The K requirement of onion plants increases with yield and its functions are linked to photosynthesis (Greenwood & Stone 1998). If K is deficient or not supplied in adequate amounts, bulb plants can be stunted, become susceptible to disease and have reduced yields (Singh & Verma 2001). Yield responses of onions to applied K would be less likely on soils with high cation exchange capacity such as certain types of clay soils, low soil moisture contents and low yielding cultivars (Boyhan & Hill 2001; Al-Moshileh 2002).

Like other macronutrients, S is a vital nutrient for life and essential for plant growth. It contributes to high crop yields and quality in three different ways: 1) it provides a direct nutritive value; 2) it improves the use efficiency of other essential plant nutrients, particularly N, P and some micronutrients, like Zn, Fe, Cu, Mn and B; and 3) it improves crop product quality by increasing protein and oil percentage in seeds, cereal quality for milling and baking, nutritional value and marketability of vegetables and fruits. In general, S has similar functions in plant growth and nutrition as N and plant requirements for S are comparable to P. Most crops remove 15 to 25 kg S ha^{-1}. Oil crops, legumes, forages, and some vegetables (onions) require more S than P for optimal yield and quality (Fan & Messick 2007). Significant increases remained restricted up to 30 kg S ha^{-1} even though application up to 45 kg S ha^{-1} consistently increased fresh and the dry yield of garlic bulbs (Jaggi & Raina 2008). Surendra (2008) also reported an increase in bulb yield of 3.78 t ha^{-1} in onion and 1.88 t ha^{-1} in garlic with higher S use efficiency due to the application of S up to 40 kg ha^{-1} over the recommended dose of NPK fertilizers. Being sulphur loving crop, sulphur response in garlic is natural and expected. Consequently, significantly increased garlic growth, bulb and foliage yields and other yield and quality attributes of the plant following S application within the range of 20 to 60 kg ha^{-1} was reported by different scholars (Nagaich *et al*. 2003; Losak & Wisniowska-kielian 2006; Diriba-Shiferaw *et al*. 2015).

Integrated nutrient management

The use of balanced sources of nutrients to obtain high yield and good quality garlic bulbs is an important practice in today's garlic production. Organic inputs are often proposed as alternatives to mineral fertilizers. However, the farmers' organic inputs, crop residues and animal manures cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials, and the high labor demands for processing and application. Therefore, most farmers in Africa fall within the two extremes of the organic to inorganic fertilizer continuum and use a combination of organic and inorganic inputs (Palm *et al*. 1997). Complementary use of chemical fertilizers and organic manures has assumed great importance nowadays to maintain as well as sustain a higher level of soil fertility and crop productivity (Shalini *et al*. 2002). Farmyard manure (FYM) is among the important soil amendments to which farmer's access has in mixed farming systems as it improves both crop productivity, and the physical and chemical conditions of soils through supplying different nutrients and organic matter (Harendra *et al*. 2009; Alam *et al*. 2010). The widespread use of FYM greatly depends, among others, on proper application methods, which increase the value, reduce costs, and enhance effectiveness (Islah 2010). Manures rich in K like wood ash and poultry manure give an increased out-turn. Well-rotted FYM is applied at the rate of 25-50 t ha^{-1} after the first ploughing or it may preferably be applied to the preceding crop (Shrestha 2007).

Both manure and chemical fertilizers have a potential role on the growth and development of crops (Shalini *et al*. 2002). The application of FYM at the rate of 20 t ha^{-1} increased garlic bulb yield significantly with increased uptake of N, P and K nutrients; the S and FYM application showed synergistic interaction effect on the uptake of S and ultimately on the bulb yield of garlic; maximum bulb yield was obtained at 40 kg S ha^{-1} with 20 t FYM ha^{-1} (Harendra *et al*. 2009). In Ethiopia, Melaku (2010) reported that application of 20 t FYM ha^{-1}, with 80 kg N ha^{-1} and 20 kg P ha^{-1} could ensure optimum total bulb yield of onion at Alage, Ethiopia. Teklu & Teklewold (2009) reported that the application of one season 2 t FYM ha^{-1} and inorganic fertilizers of 61 kg N ha^{-1} and 31 kg P ha^{-1} produced the highest bulb yield of shallot. Similarly, the application of integrated chicken manure (CM) and inorganic fertilizers (N and P) at a combination rates of 46 kg N + 20 kg P + 10 t CM ha^{-1} on both Andosols and Vertisols of Ethiopia significantly increased the growth, yields and qualities of garlic and also significantly reduced the amount of N and P fertilizers by about 50% as compared to the levels of inorganic fertilizers previously recommended for the crop (Diriba-Shiferaw 2014).

Intensive cropping, imbalanced fertilization and absence of application of micronutrients, less or no use of organic manures could result in the depletion of soil fertility (Palm *et al*. 1997). According to the report of Alam *et al*. (2010), the response of onion to micronutrients in terms of growth and yield in calcareous soils increased over the control treatment. The combination of Zn and B increased the maximum bulb yield by 49.66% over the control and on the other hand, Zn and B alone increased the bulb yield of onion by 28.64% and 27.74% over the control, respectively. Garlic plants showed differential response to different rates of compound fertilizers; significantly superior response of garlic, as observed by the vegetative growth, nutrients content and uptake of the crop, and bulb yield and quality was obtained when garlic planted in Andosol with the fertilization of D-coder compound fertilizer at the rate of 200 kg ha^{-1} which supplied 28% N + 18% P + 42% S + 0.2% Zn nutrients combination (Diriba-Shiferaw *et al*. 2013a; 2013b). In addition, integrated soil fertility management could enhance sufficient uptake of nutrients by crops (Poornima 2007). According to Poornima (2007) higher concentrations of N, P, K and S in onion plant were recorded in treatments received higher levels of K and S, which in turn resulted in higher uptake of N, P, K and S, by onion crop.

Effect of nutrition on postharvest quality and shelf life

Many external and internal factors influence both post harvest quality and shelf life of crops. According to Baligar *et al*. (2001) external factors such as soil moisture, temperature, light, best management practices, soil biological, and fertilizer materials, and their interactions with genetic, morphological, and physiological plant traits have profound effects on yield and qualities of crops. Types and rates of nutrients with varieties have great impacts on post harvest shelf life of bulb crops. Sprouting is the major factor limiting storage life of garlic bulbs (Kang & Lee 1999; Cantwell *et al*. 2003). At harvest, bulbs are in a state of innate dormancy and dormancy terminates when inner sprout growth begins. High dose of N produces quick sprouting of thick-necked bulbs during storage. Moreover, greater percentage of open thick-necked bulbs results in increased sprouting due to increased access of oxygen and moisture to the central growing point. In Ethiopia, Kebede (2003) and Gebrehaweria (2007) found that bulbs fertilized with higher amounts of N exhibited less storability with more weight loss compared to the shallot and garlic bulbs fertilized with lower amounts of N. Another factor that could be attributed to the increment in sprouting of bulbs is higher concentration of growth promoters than inhibitors in the bulbs of N fertilized plants that keep it growing (Dankhar & Singh 1991). Timing and types of various fertilizer applications have been reported to have effects on disease incidence, weight loss, and regrowth in storage (Rabinowitch & Brewster 1990).

A dry matter or total solids content is an important quality factor in many crops. Dry matter measurements also provide information on environmental factors and cultural management procedures during the production season. Dankhar & Singh (1991) investigated the effect of nitrogen and potash on the total sugar composition of different varieties of onions and found that the total sugar of bulbs decreased during storage and the reduction was higher at lower dose of nitrogen compared to its higher dose. Total sugar content during storage is considered an index of keeping quality. Changes in the carbohydrate composition of bulbs during storage were reported where the main change was the hydrolysis of oligosaccharides to reducing sugars. Salama *et al.* (1988), while evaluating storage methods for onions, observed that bulb quality decreased most rapidly when onions were stored in air at 10°C as indicated by lower concentration of sugars and greater pungency. After eight weeks, fructose levels increased rapidly and this was attributed to low temperature hydrolysis of fructans. Garlic grown on soils with balanced fertilizers and subsequent management of growth and postharvest practices recorded better bulb qualities with long storability. D-coder compound fertilizer at the rates of 200 and 400 kg ha^{-1}, which supplied N, P, S, and Zn nutrients, recorded higher percent of dry matter, total soluble solids and pungency of bulbs and lower percent in weight and diameter losses during three months of storage times (Diriba-Shiferaw *et al*. 2013b).

Bulbs of onion, garlic and shallot are routinely stored for varying lengths of time before being marketed. Even though the bulbs may be dormant during this time, flavor changes have been measured in bulbs and its pungency was found to play a very important role in the storage of bulbs (Randle & Lancaster 1995). Flavor intensity and quality do change in storage and the changes appear to be dependent on cultivar, storage duration, depth of bulb dormancy, and storage temperature. Surface discoloration, moisture loss, and microbial spoilage contribute to loss of shelf life and quality in peeled garlic cloves (Ramirez-Moreno *et al*. 2001). Other important causes of quality loss are sprouting and rooting, which occur because of high humidity conditions in plastic packaging and because of storage at higher than the recommended 0-2^{o}C (Cantwell *et al*. 2003).

Garlic crop is important in many diets, because of their nutritional significances and major economic and dietary importance to small-scale farmers; in addition to fresh consumption, the production of dried and processed garlic products for use in food preparation and as dietary health-food supplements is an important industry. The productivity and area of most of the crops grown in many parts of Ethiopia are declining due to soil degradation and the constraints of moisture and nutrients unavailability accompanying it and other poor management/cultivation practices. However, farmers continue growing crops in spite of obtaining low yields as a result of having little choices as producing the crops are vital for meeting their nutritional and economic needs. As a result, integrated soil fertility management is valuable for higher yield potential, bulb quality and environment-friendly sustainable farming systems and increase of profit margins for growers.

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