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Influence of Irrigation and Integrated Nutrient Management on Garlic (*Allium sativum* L.) Production in Ethiopia: A Review

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Abstract

Garlic (*Allium sativum* L.) is the second most widely consumed cultivar of Allium after onions in terms of production and consumption worldwide. Allium is the genus that contains garlic, which is a part of the Alliaceous family. It spread and was introduced to new countries through trade and colonization. Highlands (1500–3456 m) with subtropical to temperate climates, well-drained sandy, silty clay soils, pH values of 7, and perfect storage conditions are good for garlic cultivation. People have known that garlic is a significant spice and healing herb for over 5000 years. In Ethiopia's agroecology, garlic cultivation has a lot of potential and chances. from 16,411.19 coverage hectares in 2013/14 to 15,980 coverage hectares in 2020/21, there was a decline in garlic output. With an average productivity of 7.8 tons/ha, the Ethiopian garlic output is below the global average of 18.4 tons/ha. The nutrients from organic sources are released more slowly than those from mineral fertilizers because they must first break down with bacteria for plants to access them. Using organic sources has several advantages, including improving soil moisture capacity, rooting conditions, adding nutrients not found in mineral fertilizers, and replenishing soil organic matter. Drip irrigation systems are better suited for plants with shallow roots because they retain the nutrient solution around roots for a longer amount of time than other systems. This review article aimed to demonstrate the influence of irrigation and integrated nutrient management on Garlic production. This is particularly essential in areas where soil fertility has deteriorated.

Keywords: soil organic matter; soil moisture capacity; garlic; resource utilization; irrigation

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1. Introduction

Garlic, a member of the Alliaceae family, originated in Central Asia and has been used in China, India, and Egypt for centuries. It is the second most significant crop in the Allium family and is used as a spice for flavoring food and in medicine to treat and cure illnesses (Voigt, 2004; Labu & Rahman, 2019). Garlic thrives in subtropical to temperate regions and thrives in well-drained sandy, silty-clay soils with a pH of 7 (Alemu and associates, 2016). In 2020, 28.1 million metric tons of garlic were produced worldwide, a 3.9% increase from the previous year. China and India are the two countries in the Asia-Pacific region that use garlic extract the most, as it is a fundamental ingredient in various cuisines.

Garlic is cultivated globally, with Egypt, Thailand, China, India, Korea, and Spain being top producers. Asia produces 87% of garlic, with China and India contributing the most. Africa produces only 2.8%. China's yield is four times higher than the world average, and garlic's global area coverage increased from 1,142,220 ha in 2003 to 1,422,408 ha in 2011 (FAO 2003; FAOSTAT 2011).

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Garlic is a major bulb crop for domestic and international markets, with cash crops exported to the USA, Europe, the Middle East, and African nations for foreign money as stated by Kilgore et al. (2007). The yield disparities between Ethiopia and industrialized nations may be attributed to differences in technical resources and agricultural management practices, rather than genetic variances. Organic agriculture, as described by Foissy et al. (2013) and Jarvan et al. (2017), is based on ecological processes and ecosystem management. One useful organic fertilizer for maintaining soil fertility is FYM. Ensuring a proper equilibrium between nutrient inputs and outputs is essential for both immediate productivity and long-term viability on organic farms. Farmyard manures are the primary source of nutrients, even on small farms (Fageria, 2012; Baksiene et al., 2014). Ibrawuchi et al. (2007) found that the application of FYM may effectively alter the soil pH from an acidic condition to a neutral one. This shift in pH promotes both short-term crop productivity and long-term environmental sustainability.

Organic fertilizers release nutrients more slowly than mineral fertilizers due to microbe breakdown (Hintsa et al., 2016). However, they improve soil moisture capacity, increase crop responsiveness, add nutrients, improve rooting habitat, and replenish soil organic matter (Fairhurst, 2012). Organic fertilizers enhance microbial activity, augment soil organic matter, and provide essential macro- and micronutrients required by plants (Angin et al., 2017). Diacono and Montemurro (2011) and Fageria (2012) found that Soil organic matter plays a vital role in maintaining the sustainability of agricultural systems by improving the physical, chemical, and biological properties of the soil.

Ethiopia’s agricultural sector, which provides 40% of the country’s GDP, has to be enhanced to improve rural living conditions and economic sustainability (IWMI, 2010). Despite the country’s substantial irrigable area and water resources, Ethiopia’s agricultural sector is not entirely profiting from irrigation land and water management technology. Poor agricultural productivity is attributed to farmers’ inadequate utilization of inputs like fertilizers due to uncertain moisture availability and soil degradation. To address this, secure irrigation access and effective farmed area utilization are recommended (GTP, 2010). The food security strategy in Ethiopia’s growth plan focuses on expanding irrigated agriculture and integrated fertilizer usage.

Garlic, a crucial crop, faces various biotic and abiotic stresses, including rainfall, irrigation schedules, and insufficient or excessive mineral nutrition (Jaleel et al., 2007; Cheruth et al., 2008). Its thin root system necessitates consistent fertilizer and water application. Soil moisture levels also impact garlic quality and yield (Shock et al., 1998). Low levels lead to low yields, while high levels waste water, cause nutrient leakage, and cause rots. Variations in crop yields between seasons and sites are likely due to nutrient availability, cropping season, soil, planting date, plant population, and cultural practices. Water is the primary factor limiting agricultural and economic development during the dry cropping season Cheruth et al., 2008). Nutrient depletion in crop-producing areas, particularly in East Africa, is a significant issue due to land cultivation and soil deterioration. According to Henao and Baanante (1999), The rate of depletion is estimated to be between 47-88 kg ha^{-1} year^{-1}, with highlands experiencing up to 100 kg ha^{-1} year^{-1}. Soil erosion, P fixation, and leaching are major causes, and population pressure exacerbates the problem.

Ethiopia’s diverse agroclimatic zones impact agricultural productivity, particularly for crops like garlic, which are susceptible to soil fertility and water availability fluctuations. The growing demand for garlic has led to a shift towards integrated, sustainable farming methods. Irrigation is a major factor affecting garlic production, especially in areas with variable rainfall patterns. Effective irrigation techniques reduce water-induced stress, ensure water supply, and improve water use efficiency, making the right method essential for Ethiopia’s agroclimatic conditions. This review aims to fill a knowledge gap in Ethiopia by examining the combined effects of irrigation and integrated nutrient management on garlic production. It compiles existing knowledge, identifies research trends, and suggests synergies between these techniques for maximum garlic output, aiming to close the existing knowledge gap.

2. Methodology

Gathering the existing literature or research outputs from peer-reviewed publications is the first step in this study. A comprehensive literature search was conducted utilizing the Web of Science and Google Scholar search engines. The papers were chosen by doing targeted searches for relevant literature on soil fertility studies of garlic crops in Ethiopia in peer-reviewed journals pertaining to agronomy and soil. The following are important terms: “garlic production,” “Ethiopia,” “integrated organic and inorganic nutrient management,” “inorganic fertilizer management,” “organic fertilizer management,” “soil fertility management,” “irrigation,” and “water use efficiency.” whenever the review paper was connected to peer-reviewed literature.

2.1. Crop Over View

2.1.1. Botanical and Morphological Characteristics of Garlic

Botanically speaking, garlic is a member of the Allium family Alliaceae, which also contains essential crops of vegetables like shallots (A. asacloncum), onions (Allium cepa), and leeks (A. ameloprisum). According to Filgiuolo et al.,2001; and Ipek et al., 2003, garlic constitutes a species of diploids (2n = 2x = 16) with mandatory apomixis which reproduces through vegetative means.

Despite being propagated asexually, cultivars of garlic exhibit significant phenotypic variation. These cultivars are highly adaptable to a variety of settings. Garlic plants have thin, tape-shaped leaves that are roughly 30 cm long, just like onions. Roots can be found up to 50 cm or somewhat deeper. White-skinned bulbs, or heads, are separated into pieces known as cloves. A white or reddish papery coating, or “skin,” covers the six to twelve cloves that may be present on each head (Hector *et al*., 2012).

It is anticipated that the sexual propagation of garlic will promote genotype-to-genotype genetic trait exchange and enhance garlic cultivars by classical breeding (Kamenetsky et al., 2004). Cloves are planted to spread garlic instead of actual seeds. Typically, each bulb is planted separately and has twelve or more cloves within. The best garlic bulbs should only be planted with their larger outer cloves since larger cloves produce larger, mature bulbs when harvested.

When the bulb is ready to be planted, do not split it; doing so too soon can reduce yields. Choose “seed bulbs” that are healthy, big, smooth, and disease-free. Dig a hole or trench, carefully set the unpeeled clove into it with the pointed side up (the ends of the scar stem down), and cover it with dirt to plant garlic properly. A straight neck is guaranteed when the cloves are arranged upright (McLaurin, 2012).

Common garlic cultivars have a somatic chromosome number of 2n=16, with some Campania-based plants being tetraploid (4n=32) and some possibly triploid. Garlic frequently has chromosomal abnormalities as a result of many translocations involving eight or even ten chromosomes. According to Jo *et al*. (2012), several sterile cultivars have a normal karyotype.

2.1.2. Origin, Domestication, and Distribution

Since ancient times, garlic (*Allium sativum* L.) has been grown throughout the world, but primarily in Asia (Anand et al., 2017). Owing to its curative and preventative qualities, it is used as a traditional medicine in addition to being a food ingredient. Garlic has a pungent flavor that comes from a variety of organosulfur compounds, including cycroalliin, diallyl disulfide, allicin, and alliin, which are good for you. According to Ryu and Kang (2017), these substances exhibit anti-inflammatory, antibacterial, and anticarcinogenic properties.

These properties have contributed to an increase in the consumption of garlic among health-conscious consumers (Suleria et al., 2015). Most nations in both the tropical and temperate zones cultivate garlic. The developing world dominates the world’s garlic trade, and over the last 10 years, their fraction of trade has expanded at the cost of the developed world (FAO, 2004). The top three nations’ production quantities in 2019 were 23.26 million metric tonnes for China, 2.91 million metric tonnes for India, and 466.39 thousand metric tonnes for Bangladesh, according to FAOSTAT 2019. There is a concentration of garlic production in the United States and abroad. China is the second-largest garlic exporter after Spain. Commercial agriculture takes occurs in Egypt, Ethiopia, Algeria, Sudan, Morocco, Tunisia, Niger, Tanzania, Nigeria, and Kenya in Africa. In Africa, Egypt is the biggest producer and exporter. Nigeria produces relatively little; the bulk is cultivated in the northern states, such as Kano, Kaduna, Kebbi, Sokoto, Jigawa, Bauchi, Katsina, and Zamfara States (Kudi et al., 2008).

In the past, garlic traveled to the Mediterranean. It is a crop that has been farmed since 1600 BC in Egypt and is also considered ancient in China and India. Nowadays, garlic is grown in both hemispheres, from the equator to latitudes around 50°, although it is most extensively eaten in Latin America, China, and the Mediterranean area. Garlic is cultivated throughout tropical Africa, notably in the Sahel and at high elevations in East and Southern Africa during the cold season. With a considerable level of genetic variation in the local cultivars, it is a commonly farmed crop in the savanna zone. Hot, steamy lowlands are seldom, if ever, home to it.

2.1.3. Production and Productivity of Garlic in Ethiopia

In fact, several options and possibilities in Ethiopian agricultural ecology when it comes to garlic production. Garlic production in Ethiopia decreased from 16,411.19 coverage hectares in 2013–14 to 15,980 coverage hectares in 2020–21, however current output is still below potential (CSA, 2021; Shege et al., 2021). With about 78% of the world's garlic output (22.27 million tons), China is the biggest producer in the world (Desta et al., 2021). The United States, Russia, the Republic of Korea, Bangladesh, Egypt, Spain, India, Myanmar, and Uzbekistan were ranked after China (FAO 2023). Ethiopia produced a pitiful 113,928.43 tons total from 14,576 hectares of land, with an average yield of 7.8 tons/ha (FAO 2023). This indicates that Ethiopia produces less garlic than the world average of 18.4.

2.1.4. Importance of Garlic

For thousands of years, people have employed natural products from plants, animals, and microorganisms, either in their pure forms or as unrefined extracts, to treat a wide range of illnesses (Parekh and Chanda, 2007). One plant that has been used for centuries to treat infectious disorders is garlic (*Allium sativum* L.), which has been the subject of extensive research for several years (Onyeagba et al., 2004). There has long been debate concerning the taxonomic classification of garlic and related taxa. At least 33 sulfur-containing compounds, multiple enzymes, the minerals calcium, iron, potassium, magnesium, selenium, and zinc, as well as fiber, water, and the vitamins A, B1, and C, are all present in garlic. Additionally, garlic contains the following 17 amino acids: proline, glycine, alanine, cysteine, valine, methionine, isoleucine, leucine, tryptophan, swine, glutamine, threonine, histidine, arginine, aspartic acid, and phenylalanine (Josling, 2005). Garlic's strong smell and many of its therapeutic properties are attributed to its higher concentration of sulfur compounds than any other Allium species.

With good reason, garlic is recognized to be among the most natural and remarkable plants with healing capabilities. It contains tumor-fighting capabilities and the capacity to prevent and destroy germs, and fungus, decrease the levels of cholesterol in the blood and glucose levels, and also reduce clotting of the blood. To prevent sickness and protect health, it may help improve the immune system (Abdullah et al., 1988). It may speed up the body's removal of waste products by activating the lymphatic system. It is also known to be a potent antioxidant that defends cells from harm caused by free radicals. Certain malignancies, heart disease, strokes, and viral infections may all be averted with its support. About two hundred distinct chemicals present in garlic alone can guard the human body against a broad variety of ailments. Garlic's sulfur-containing components defend the human body by stimulating the development of certain beneficial enzymes (Mansell and Reckless, 1991).

2.2. Climatic Requirements and Adaptation

One of the most important Allium vegetable crops globally both in terms of production and financial value is garlic. There is a vast geographical range for the adaption and cultivation of garlic. Leading manufacturers internationally include Egypt, Thailand, China, India, Korea, and Spain. Some countries, such as China, produce more garlic than dried onions. Asia produces 87% of the world's garlic, with China and India being the two biggest producers, jointly accounting for 78% of the crop. Africa yields just 2.8% of the world's total output of garlic.

One of the major bulb crops grown in Ethiopia for domestic use is garlic, which provides a living for a large number of peasant farmers throughout the nation (Metasebia and Shimeles, 1998; Getachew and Asfaw, 2000). In Ethiopia and throughout the world, garlic is a significant vegetable crop. Garlic average output climbed in Ethiopia from 11,845.53 hectares in 2015/16 to 15,381 ha in 2016/17. Approximately 50,683 farmers grew garlic in the Eastern Hararghe Zone, even though data regarding average productivity, and production are not available (CSA, 2017).

While the total amount of garlic produced climbed from 79,421 to 222,548 tonnes of bulbs in 2012/13, with an increase in land from 6,042 ha in 2001–02 to 21,258 ha in 2012/13, its productivity fell from 13.20 to 10.47 t ha^{-1}, correspondingly (CACC, 2002; CSA, 2012). The majority of garlic grown for the domestic market is grown in homestead gardens owned by subsistence farmers in many other highland parts of Ethiopia; yields are generally poor, averaging about 11.7 t ha^{-1} (CSA, 2010) and 11.31 t ha^{-1} (CSA, 2012) in East Showa. More than 58% of the whole yield was used for domestic use, 24.5% for the market, and 16% for seed. Garlic is utilized in this nation to make indigenous medicines and as an ingredient in the stew known as "wot" (CSA, 2010). The country's mid- and highlands are where garlic is primarily grown (Getachew and Asfaw, 2000; CACC, 2002). The majority of garlic grown for the domestic market is grown in homestead gardens owned by subsistence farmers, who primarily grow it as a cash crop to export for foreign exchange.

The most frequently planted Allium species in Ethiopia is garlic, which is very tolerant of a variety of temperatures and soil conditions. Climate-wise, the ideal sites to produce garlic are those with a reasonably mild winter with some rainfall and a bright, dry summer that is excellent for bulb growth and harvesting (Brewster, 1994; Lemma and Herath, 1994). Garlic plants, according to Rubatzky and Yamaguchi (1997), are exceptionally hardy and can sustain low temperatures seven below freezing but they might not survive the winter in some severely cold areas. Most nations from the equator to around 500 latitudes produce garlic, which grows best in temperatures between 12 and 24 ^{0}C (Nonnecke, 1989).

Bulbs need high temperatures to thrive, but in the early stages, colder temperatures stimulate vegetative growth; altitudes between 500 and 2000 meters amsl offer optimal conditions for development (Rice et al., 1990). The development of bulbs and vegetative growth are inhibited by high humidity and precipitation. Plants are quickly affected by waterlogging and need water. Therefore, moisture in the upper 30 cm of the soil's surface should be maintained around the field's capacity for growth to produce maximum output (Brewster, 1994; Rubatzky and Yamaguchi, 1997). As a high-value crop, garlic requires rich soil, adequate drainage, and friable soil preferably with a large level of organic matter, and water that isn't lacking until two weeks before harvest. The crop likes soil with a pH of 6.5-7.5 since it is prone to greater acidity, and an excess of water supply two weeks before harvesting time impacts the storage quality (Bachmann, 2001; Potgieter, 2006. The crop generates a coarse root system, but it also requires some hardness the soil has to be well-drained and free of compaction for excellent root-to-soil contact. Bulbs grow discolored in poorly drained soil; they are distorted and challenging to harvest in clay loam soil.

2.3. Nutrient Requirements of Garlic Crop

According to Campbell *et al*. (2004), a sustainable agricultural system is profitable, produces wholesome, safe food, preserves resources, and improves the environment. The foundation for increasing agricultural yield from currently farmed land is fertilizers (Ryan, 2008). Due to the negative effects that excessive crop nutrient consumption has on the environment and economy, balanced fertilization is necessary, and crop nutrient requirements should be determined by physiological needs and anticipated yields (Ryan, 2008). The soil's fertility level, the crop's variety, the reason for planting, etc., all affect how much fertilizer is needed for garlic crops. The fertility level of the soils is one of several aspects that considerably impact the production of garlic crops primarily due to the exceptionally large amounts that are picked out of soils in contrast to the other essential nutrients, the most important nutrients, P, and K are becoming increasingly scarce in the mineral-rich soils of many African countries (Marschner, 1995; Rao et al., 1998), and this is also common for Ethiopian soils (Yohannes, 1994). Most Ethiopian soils are nutrient-deficient, mainly in nitrogen and phosphorus, according to soil fertility studies done at various locations for distinct crops. These tests have shown large production responsiveness from applied phosphate and nitrogen fertilizers (Asnakew and Tekalign, 1991; Berga et al., 1994; Yohannes, 1994).

Because of their short and without branch systems of roots, bulb crops are more sensitive to nutrient withdrawal than most other agricultural plants, particularly the stationary kinds. As a consequence, they need more fertilizers, which they typically react to effectively (Brewster, 1994). Bulb crops are high-value crops whose better production and quality are major economic factors. Depending on the soil's nutritional quality, garlic needs a moderate to high quantity of fertilizer (Berga et al., 1994). Currently, numerous types of fertilizers are administered to boost garlic yields. Because the different fertilizers provide variable levels of plant nutrients, they have unique impacts on the soil environment. The quality of the crop must be protected in combination with human attempts to boost garlic yields by substantial fertilizer application (Cantwell et al., 2006). Because they are heavy feeders, bulk crops require sufficient N, P, and K in the form of inorganic, organic, or a mix of fertilizers. The production, quality, and storability of bulbs are all adversely influenced by inadequate concentrations of these nutrients in the soil (Gubb and Tavis, 2002).

To encourage soil aggregation and improve aggregate stability, organic matter (compound) is added to the soil along with compost and created by the ensuing biological activity (Bot, 2005). Composting causes instantaneous, calculable changes in the quantities of nutrients, trace metals, and other chemical components in soil, according to Buzie-Fru (2010). According to Fijalkowski *et al.* (2012), compost affects the pH of the soil because it contains both carbonate and organic matter, which raises the pH while acting as a buffer to keep the system at a neutral level. Research suggests that adding organic materials regularly, especially composted ones increases the physical fertility of the soil primarily by enhancing aggregate stability and reducing soil bulk density (Diacono and Montemurro, 2011). However, composts can directly combat disease, encourage the growth of microorganisms that compete with them, and help plants build disease resistance (Ebrahimi *et al.*, 2018).

2.4. Integrated Use of Organic and Inorganic Fertilizers

One of the most crucial techniques in garlic production today is the usage of well-balanced sources of nutrients to generate high-yield, high-quality garlic bulbs. It's typical to see proposals for organic inputs in place of mineral fertilizers. However, owing to their low nutrient content, restricted availability, and labor-intensive processing and application requirements, farmers' employment of organic inputs, crop wastes, and animal manures is inadequate to meet crop nutrient needs across vast regions. As a consequence, most African farmers apply a mix of organic and inorganic inputs (Palm et al., 1997). To retain a greater enhancement of soil fertility and crop production, it is increasingly important to apply chemical fertilizers and organic manures in complementary methods (Shalini et al., 2002).

Farmyard manure (FYM) is one of the most important soil amendments accessible to farmers in mixed agricultural systems. It boosts crop yield and improves the physical and chemical qualities of soils by adding organic matter and other nutrients (Harendra et al., 2009; Alam et al., 2010). One option for achieving a reasonable output level with a significant amount of fertilizer that leads to sustainable agriculture is the integrated nutrient supply technique (Bhagwan et al., 2012). The current combination application is appreciated because there isn't enough organic material. According to

Verma *et al*. (2013), plants could obtain all of the necessary nutrients for growth and development when organic and inorganic fertilizers were applied together. Thus, it is essential to combine VC with mineral N fertilizer to boost plant productivity while lowering environmental pollution. Increasing the yield of garlic in the Eastern Hararghe Zone is a major goal of crop research. According to Riba et al. (2013), garlic plants responded differently to various rates of compound fertilizers.

2.5. Effects of Fertilizer on Garlic Production

According to Foissy et al. (2013), organic farming is a production technique that relies less on the external flow of agricultural inputs and more on ecological processes and ecosystem management. According to Jarvan et al. (2017), one of the most helpful organic fertilizers for conserving soil fertility in alternative agricultural systems is FYM. The maintenance of soil organic matter and the balance of organic carbon are closely connected to the preservation and promotion of soil potential fertility (Baksiene et al., 2014). Even on modest farm holdings, farmyard manures are the principal source of nutrients (Fageria, 2012). According to Ibrawuchi et al. (2007), the injection of FYM altered the pH of the soil from an acidic condition to a neutral one.

When compared to mineral fertilizers, the release of nutrients from organic sources occurs more slowly since the nutrients need to break down with microbes to become available (Hintsa Meresa *et al*., 2016). Using organic sources improves soil moisture capacity, increases crop responsiveness to mineral fertilizers, adds nutrients that mineral fertilizers do not possess, improves rooting habitat, and replenishes soil organic matter (Fairhurst, 2012). Studies revealed that the addition of organic fertilizer enhances the organic matter of the soil, promotes the growth of microbes, and delivers micronutrients as well as macronutrients required by the plant in a more effective method (Angin et al., 2017). Diacono and Montemurro (2011); and Fageria (2012) showed that soil organic material (SOM) plays a critical role in sustaining the sustainability of agricultural systems by increasing soil's physical, chemical, and biological qualities.

Appropriate management of nitrogen supplies and preservation of soil fertility are essential for sustained crop cultivation. However, a key concern for many countries striving to sustain agricultural production and output is the loss of soil fertility. On the other hand, utilizing inorganic fertilizers exclusively could result in rapid increases in crop production. According to Doran and Parkin (1994), soil organic matter, which also functions as a substrate for soil microbes and a storehouse of plant nutrients, is a crucial factor in determining the quality of the soil (Dutta et al. 2003). To maintain garlic output and improve soil quality, organic manures must be added. Compared to artificial fertilizers, organic manure has a variety of drawbacks, such as poor nutrient content, sluggish breakdown, and varying nutritional compositions depending on its organic ingredients (Han *et al*. 2016). According to several writers, using chemical fertilizers in combination with organic manures reduces the harm that chemical fertilizers due to agroecology while simultaneously increasing yield, nutrient uptake, and quality (Chand *et al*., 2006; Thangasamy and Lawande, 2015; Han *et al*., 2016). Therefore, to improve garlic yield and maintain soil health, an integrated application of mineral fertilizers, organic manures, and biofertilizers is necessary.

Table 1. Effects of Integrated Organic and Inorganic Fertilizers on Garlic Production in Ethiopia.

Citation	Fertilizer Combination	Bulb Yield (t/ha)	Key Findings
Alemayehu & Abate (2021)	112–37–16 kg/ha NPS + 15 t/ha cattle manure	22.05	Highest bulb yield and net benefits observed; marginal rate of return exceeded 1.492%.
Shumbulo et al. (2024)	150 kg/ha NPS + 15 t/ha chicken manure	20.27 (total),19.52(marketable)	Combined application resulted in maximum marketable bulb yield and total yield.

Tesfaye et al. (2024)	120 kg/ha NPS + 10 t/ha cattle manure	Not specified	Significant improvements in garlic yield and quality parameters.
Assefa et al. (2015)	130 kg/ha NPS + compost	4.76	Higher yield compared to control; compost application improved soil fertility.
Alemu-Degwale (2016)	10 t/ha vermicompost	Not specified	Vermicompost application enhanced garlic growth and yield.

2.6. Irrigation and Field Management

Ethiopia is the second most populated nation in Sub-Saharan Africa. Its subsistence rainfed-based farming system wouldn't be able to provide the nation's food needs owing to regional and seasonal rainfall unpredictability, degradation of the soil, fertility depletion, and the consequences of climate change (Zerssa et al., 2021). Furthermore, irrigation users' yearly income might be enhanced eight times more than non-irrigation users' (Berhe et al., 2022).

Watering garlic takes two to five centimeters of water every week. Water will affect yield most before bulbing, much like nitrogen does. Even though bulbing requires enough moisture, irrigation should be discontinued at least two weeks before the anticipated harvest date. Late-season watering usually results in skin discoloration and lower quality (Goldy, 2000). According to studies done in Australia by Hickey (2012), water stress in garlic crops should be avoided before they show the first signs of maturity for maximum yields. Since the fibrous root system is limited to the top layer of soil, enough water needs to be added to the soil to moisten it to this depth. When the first indications of maturity appear (yellowing of the tips or softening of the necks), stop watering. Keep cultivation shallow to prevent root trimming if it's required for weed control or water infiltration. You could use a knife. Hand hoeing is required to get rid of any weeds that have sprouted up in the row (Hickey, 2012).

2.6.1. Nutrient Use Efficiency and Management of Garlic in Ethiopia

Ethiopia has a long history of using traditional irrigation techniques. Simple river diversion remains Ethiopia's main irrigation technique (Awulachew et al., 2010). It is estimated that Ethiopia has 5.3 million hectares of potential for irrigation. Of the potential 3.7 million hectares, 1.6 million are accounted for by groundwater and rainfall collection systems, while the remaining 3.7 million hectares are accounted for by surface water collecting methods (small, medium, and large scale). As of 2015, only around 12% of the 857,933 hectares of irrigated land have been done thus (Molden et al., 2010). Water resources must thus be carefully managed in order to increase the area under irrigation while utilizing the water that is available (Oki and Kanae, 2006; FAO, 2011).

Therefore, increasing cropping intensity in irrigated regions and yields in both rain-fed and irrigated agriculture using a variety of techniques and technologies are the most realistic strategies to attain food security (Diriba, 2016; Awulachew et al., 2010; Fraiture and Perry, 2007; Seleshi and Zanke, 2004). Crop water consumption efficiency may be greatly increased by properly scheduling irrigation, which is based on crop evapotranspiration (Incrocci et al., 2014; Hanson et al., 2003). Ethiopia has traditionally employed irrigation at different agricultural levels, but no efficient or well-managed irrigation water system exists. Very little or no information is available about crop management practices and the appropriate use of irrigation water for the country's rapidly expanding irrigation fields.

Garlic is vulnerable to water stress at every stage of growth, but especially during the bulb-formation stage, because of its shallow roots (Singh et al., 2010; Silabut et al., 2014). The amount of irrigation required depends on the kind of soil and the climate. However, most soils require 2.5 cm of water every week during the growing season. Water twice a week after planting until over 80% of the seeded cloves emerge for reliable and rapid sprouting. After that, the frequency can be reduced to once a week. In accordance with Singh and Chand (2003) and Yayeh et al. (2017), fluctuations in soil moisture between dry and wet circumstances may cause irregular growth and the creation of deformed bulbs.

Despite its importance, vast production potential, and strong consumer demand, garlic's present productivity and output are limited and still seasonal. Low soil fertility, which is mostly caused by crop yield losses brought on by crop waste expulsion from farmland, crop nutrient absorption from the soil by crops, and erosion of surface soil, is one of the issues impeding the productivity of various crops in Ethiopia (Abay, 2016; Belay, 2015).

Crop rotation, intercropping, farmyard waste, and fallowing are all practices Ethiopian farmers have long used to maintain or increase soil fertility and lessen these problems (Befekadu et al., 2017). Manure application enhances the soil's properties and nutritional state, increasing soil fertility and garlic output. Similar results were reported by Shivananda (2002), who discovered that adding organic elements to the soil, including compost, green manure, or farm yard manure, in addition to inorganic fertilizer improved the soil's physical characteristics. Additionally, the author discovered that when 50% of the fertilizer was organic and 50% was inorganic, crops absorbed much more nitrogen, phosphorus, potassium, zinc, manganese, copper, and iron.

Nutrient utilization efficiency(NUE), depends on the plant's ability to efficiently take nutrients from the soil as well as moisture availability and internal transit, storage, and remobilization of nutrients. Since plants absorb considerable amounts of nitrogen and phosphorus from the soil, these nutrients are regarded as the main macronutrients. Proper application of these nutrients can enhance garlic development and yield (Mulatu *et al*., 2014). Accordingly, studies carried out in several parts of Ethiopia by Diriba *et al*. (2015) showed that applying NPS in combination at varying rates of N, K, P, and S kg/ham increased the growth and yield potential of garlic. It is common practice to overspray N fertilizers in an attempt to generate large garlic crops. Because of the high amount of N applied, a significant portion of the applied N has already accumulated in the soil, resulting in low N usage efficiency. In addition, additional N may be lost to the atmosphere and groundwater (Jiang *et al*., 2013).

2.6.2. Concept of Deficit Irrigation

Massive global change in the climate combined with a steadily increasing world population have a catastrophic impact on agriculture, leading to drought issues that further exacerbate the world's scarce water supplies (Chai et al., 2016; Hussain et al., 2009). Water is the main factor limiting agricultural yield (Steduto et al., 2012). FAO (2006) projected that by 2030, developing countries will require 15% more water for agriculture. Over 95% of Ethiopia's agricultural output, according to IFAD (2005) and Zerssa et al. (2021), relies on the country's varied patterns of precipitation, both in time as well as space. Furthermore, when competent water management techniques are implemented, irrigation users' yearly revenue might increase eight times faster than non-irrigation users (Gebremeskel et al., 2022). However, small-scale irrigation systems function poorly (Abera et al., 2019; Habtu et al., 2020). Enhanced evapotranspiration reference (ETo) prediction techniques are necessary for accurate irrigation water demand estimation (Qiong et al., 2022).

The lack of consideration for crop demands or scarce water resources by farmers applying excessive volumes of water under uncontrolled flooded irrigation has resulted in low crop productivity and economic return (Beyene et al., 2018). According to Doro (2012), mismanaged irrigation might reduce crop output by as much as 60% when it comes to full evapotranspiration (ETc). The distinctive features of flooding irrigation, according to Wang et al. (2020), include low water homogeneity, difficulties managing the water, and a high rate of evaporation, which leads to little water usage efficiency as a consequence, it's important to boost water usage efficiency by using the best water management strategies, such as deficit irrigation, postponing watering until necessary, and using effective irrigation techniques. For improved crop development and productivity, a comprehensive root zone system that optimizes the relationship between soil, water, plants, and atmosphere is necessary (Fanish, 2013).

Deficit irrigation (DI) is a technique of improvement whereby irrigation is applied during a crop drought-sensitive growing period. Outside these periods, provided rainfall supplies a minimum water supply, irrigation is modest or even unneeded. Water limitation, sometimes throughout the vegetative phases and the late-ripening season, is confined to drought-tolerant phonological stages. Cumulative irrigation input is consequently not proportionate to irrigation demand through the crop's period. Although this ultimately adds to plant stress due to drought and consequently lack of production, DI optimizes the efficiency of irrigation water, which is the primary limiting factor (Abdalhi, and Jia, 2018). One strategy to increase water yield while lowering irrigation application is deficit irrigation (DI). Crop irrigation requirements in the past did not take the availability of water supply into account. These days, full irrigation is viewed as an unnecessary luxury that can be curtailed with little to no impact on a profitable crop (Sezen *et al*., 2019).

2.6.3. Water Use Efficiency

According to Descheemaeker *et al*. (2013), boosting water productivity is crucial to better water management for food security, sustainable agriculture, and the health of ecosystems. Ethiopia now withdraws less water for agriculture and other uses each year than it does from renewable resources; this poor water use efficiency will surely represent a challenge to the region's sustainable water management and usage (Gebrehiwot and Gebrewahid 2016). Using lakes and rivers, conventional surface irrigation has been widely used in Ethiopia. Crop water productivity implementation follows basic guidelines (Teshome *et al*. 2018).

A significant term in the evaluation of DI approaches is crop water efficacy (WP) or water use efficiency (WUE), which was discussed by Molden (2003). In terms of kilos per m^3, water efficiency is defined as the amount of marketable yield (Ya) divided by the volume of water utilized by the crop (ETa): WP = Ya /Eta ETa refers to the quantity of water lost throughout the growing period as a consequence of crop transpiration or soil evaporation. In experiments, it is often impossible to discern between these two processes, so they are included together under the umbrella designation of evapotranspiration (ET) (Allen et al., 1998).

WP is applied as a benchmark to determine the highest water efficiency level in the CWP function. The following Figure depicts the logistic form of the CWP function (Hanks et al., 1969; Hanks, 1974). Plotting relative yield (Yrel: ratio of actual yield, Ya, to maximum yield under defined agronomic circumstances, Ym) versus relative evapotranspiration (ETrel: ratio of actual evapotranspiration, ETa, to crop ET under non-stressed, standard conditions, ETc) makes its axes dimensionless.

Figure 1. An agricultural production of water (CWP) function's basic shape. There is a variance in the proportional widths of sections (a), (b), (c), (d), and (e). Relative evapotranspiration is the ratio of the seasonal quantity of water evapotranspired, (ETa) to the season crop water demand (ETc). Relative yield is the ratio of actual (Ya) to potential yield (Ym) under specified agronomic situations.

Table 2. Water Use Efficiency in Garlic Production under Different Irrigation Practices in Ethiopia.

Study	Irrigation System	Deficit Irrigation Level	Water Use Efficiency (WUE)	Key Findings
Ayele (2023)	Conventional Furrow Irrigation (CFI)	85% ETc	Not specified	Moderate deficit irrigation (85% ETc) maintained yield with improved water use efficiency.
Ayele (2025)	Alternate Furrow Irrigation (AFI)	70% ETc	31.52 kg/mm	AFI at 70% ETc achieved highest irrigation water use efficiency (IWUE).

Ilmi (2025)	Alternate Furrow Irrigation (AFI)	100% ETc	28.64 kg/mm	AFI at 100% ETc provided comparable yield with significantly reduced water use.
Tefera (2021)	Not specified	20%above recommended ASMDL	Not specified	Reducing soil moisture depletion level by 20% increased WUE.

Note: ***ETc refers to crop evapotranspiration; ASMDL refers to allowable soil moisture depletion level.***

The relationship between water usage and growth, especially the formation of dry matter, is referred to as water use efficiency. The crop dry matter or yield produced per unit of water utilized by the plant is the expression used to represent water usage efficiency (Mokenen, 2011). Water use efficiency can be altered by raising the plant's water consumption or by promoting the plant's growth and production. Water consumption efficiency is positively impacted by soil management techniques like tillage and residue management as well as plant nutrition techniques like adding nitrogen and phosphorus. Adopting deficit irrigation and proper irrigation schedules could help increase the effectiveness of water use (Jones, 2004). The notion of nutrient utilization efficiency (NUE) illustrates how crops can take in and utilize nutrients for optimal yields. Nutrient uptake, assimilation, and utilization are the three primary plant activities that make up the NUE concept (Gonzalez, 2017).

Table 3. Summary of Key Findings on Garlic Production in Ethiopia.

Citation	Focus Area	Key Findings
Ayele (2023)	Deficit Irrigation	✓ 85% ETc under Conventional Furrow Irrigation (CFI) achieved 8.2 t/ha yield with 7.8% loss from full irrigation. - 85% ETc under Alternate Furrow Irrigation (AFI) saved 50% water but incurred 19% yield loss. - Severe deficit (55% ETc) drastically reduced yield by 37.5%.
Ayele (2025)	Irrigation Techniques	✓ 85% ETc under CFI optimized water use without compromising yield, establishing an efficient irrigation strategy for sustainable garlic production in water-limited regions.
Alemayehu &Abate (2021)	Integrated Nutrient Management	✓ Combined application of 112-37-16 kg/ha NPS inorganic fertilizers with 10-15 t/ha cattle manure resulted in the highest bulb yields (18.03-22.05 t/ha), net benefits (Ethiopian Birr 509,456-626,814 per hectare), and marginal rate of returns (1,492.35-2,005.15%).
Shumbulo *et al.* (2024)	Integrated Fertilizer Levels	✓ Integrated application of NPS fertilizer and chicken manure improved garlic yield and quality. Specific fertilizer combinations and application rates were found to be effective for optimal garlic production in southern Ethiopia.

Challenges and Knowledge Gaps

Despite the advantages of INM and optimal irrigation, a number of problems still exist:

- ✓ Due to resource limitations, suggested procedures have not been widely adopted.
- ✓ absence of norms particular to Ethiopia's many agro-ecological zones.
- ✓ Long-term research is required to evaluate how sustainable these techniques are.
- ✓ To increase garlic productivity, these deficiencies must be filled with focused research and extension activities.

3. Conclusions

Garlic is the most important crop grown with alliums; onions are the most important crop worldwide. Its main uses in modern medicine are as a spice in cuisine and to treat and cure a variety of illnesses. Garlic thrives in highlands (1500–3456 m), but it grows best in areas with temperatures between 12 and 24 degrees Celsius, well-drained sandy, silty soils, and a pH of 7. It also stores incredibly well. Alemu and associates (2016). The FAO estimates that 28.1 million metric tons of garlic were produced worldwide in 2020, an increase of almost 3.9% from the year before. Due to the wide range of uses for garlic in the food and medical sectors, which are propelling the market globally, there has been a significant increase in both the area harvested and production.

Important variables affecting garlic production are identified in the review, including nutrient delivery techniques, soil fertility, and water availability. It talks about how different integrated nutrient management techniques, such as cover crops, crop residue integration, and organic and inorganic fertilizers, affect the quantity and quality of garlic produced. The review also looks at how various irrigation techniques, like drip irrigation and furrow irrigation, might maximize garlic yield and water use efficiency.

Considering that over 80% of Ethiopia's population makes their living from agriculture, which also accounts for 40% of the country's GDP, raising crop yields in Ethiopia is an important way of improving both the standard of living for those living in rural areas and the nation's economic sustainability. Despite Ethiopia possessing potentially abundant irrigable land and water supplies, the country's agricultural industry does not yet fully benefit from irrigated agriculture and the technologies for managing water and farmland utilization. Ethiopia has unusually low agricultural production as a result. Utilizing nutritionally balanced sources is crucial in today's garlic growing to ensure big harvests of healthy garlic bulbs. It is normal practice to suggest mineral fertilizers instead of organic inputs. However, farmers' organic inputs, crop wastes, and animal manures cannot provide crop nutrient demands across vast areas because of the constrained quantities available. The labor-intensive production and use of the resources, together with their low nutritional value. Because of this, most African farmers apply a combination of organic and inorganic inputs, putting them in the middle of the organic-to-inorganic fertilizer continuum.

To sum up, the review of the literature indicates that improved irrigation and integrated fertilizer management are essential for increasing garlic output in Ethiopia. The research emphasizes how crucial it is to have a comprehensive strategy that incorporates effective irrigation techniques with suitable fertilizer management techniques. The assessment emphasizes the necessity of recommendations that are site-specific and take into account the various agroecological zones and soil types found in Ethiopia. The report also highlights the potential advantages of sustainable farming methods and organic inputs in enhancing soil health and reducing environmental effects. It urges more studies to close the knowledge gaps that now exist, especially about the long-term consequences of integrated techniques on garlic output and the financial ramifications for farmers.

In general, this review offers significant perspectives to farmers, academics, and policymakers who are looking for effective and sustainable ways to increase garlic production in Ethiopia. The agriculture industry may boost yields while also advancing resource efficiency and environmental sustainability by combining nutrient management with irrigation techniques.

4. Future Directions

Future research should explore the impact of different irrigation schedules, deficit irrigation, optimal timing of irrigation, organic and inorganic fertilizers, biofertilizers, micronutrient supplementation, long-term effects of inorganic nitrogen management practices, interactions between soil microorganisms and garlic plants, and the potential of soil amendments to enhance garlic productivity. It is also important to study the adaptability of different garlic varieties to varying climatic conditions and the resilience of garlic crops to water stress and nutrient deficiencies under changing climate scenarios. Collaborative research involving agronomists, soil scientists, and plant physiologists is crucial for advancing our understanding of garlic production and sustainable management. This will help to improve the quality and yield of garlic, while also promoting sustainability and environmental sustainability.

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References

1. Abay A (2016). Assessment of soil fertility status of different types of soils in selected areas of Southern Ethiopia. Journal of Natural Sciences Research 6(1):2224-3186
2. Abdalhi, M. A., & Jia, Z. (2018). Crop yield and water saving potential for AquaCrop model under full and deficit irrigation managements. *Italian Journal of Agronomy*, *13*(4), 267-278.
3. Abdullah TH, Kandil O, Elkadi A, Carter J. (1988). Garlic revisited: therapeutic for the major diseases of our times? *J Natl Med Assoc*. 80:439-445.
4. Abedi, T., A. Alemzadeh. and S. A.Kazemeini. (2010)**.** Effect of organic and inorganic fertilizers on grain yield and protein banding pattern of wheat. *Aust. J. Crop Sci*. 4: 384-389.
5. Abera, A., Verhoest, N.E.C., Tilahun, S.A., Alamirew, T., Adgo, E., Moges, M.M., Nyssen, J., (2019). Performance of small-scale irrigation schemes in Lake Tana Basin of Ethiopia: technical and socio-political attributes. Phys. Geogr. 40, 227–251.
6. Alam, M. S., Rahim, M. A., Bhuyan, M. A. H., Simonand, P. W., & Malek, M. A. (2010). Effect of spacing on growth and yield of two lines of garlic under dryland conditions. *Journal of Agroforestry and Environment*, *4*, 151-154.
7. Ali, M.E., Islam, M.R. and Jahiruddin, M. (2009). Effect of Integrated Use of Organic Manures with Chemical Fertilizers in the Rice-Rice Cropping System and Its Impact on Soil Health. *Bangladesh Journal of Agricultural Sciences*, 34, 81-90.
8. Alimi, T., Ajewole, O.C., Awosola, O. and Idowu, E.O. (2007). Organic and Inorganic Fertilizer for Vegetable Production under Tropical Conditions. *Journal of Agricultural and Rural Development,* 1, 120-136.
9. Allen, J. (2009). Garlic production. Factsheet, Garlic production, order number 97-007. www.omafra.gov.on.ca/english/crops/facts/09-011w.htm.
10. Allen, R.G., Pereira, L.S., Raes, D., Smith, M., (1998). Crop Evapotranspiration—Guidelines for Calculating Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy.
11. Anand M, Sankari A, Anita B. Influence of integrated nutrient management for garlic under Nilgiris condition. International Journal of Current Microbiology and Applied Sciences. (2017); 6(12):3833-3838.
12. Angin, I., Aslantas, R., Gunes, A., Kose, M., Ozkan, G. (2017). Effects of sewage sludge amendment on some soil properties, growth, yield, and nutrient content of raspberry (*Rubus idaeus* L.). Erwerbs-obstbau; 59(2):93-99.
13. Asnakew, W., Tekalign, M., Mengesha, B., & Tefera, A. (1991). Soil fertility management studies on wheat in Ethiopia. *Wheat research in Ethiopia: IAR/CIMMYT*.
14. Awulachew, S.B., Merrey, D., van Koopen, B., Kamara, A., Penning de Vries, Frits, Boelee, E. (2010). Roles, constraints, and opportunities of small-scale irrigation and water harvesting in Ethiopian agricultural development: Assessment of existing situation. ILRI workshop, Addis Ababa, Ethiopia.
15. Bachmann J (2001). Organic Garlic Production. National sustainable agriculture information service. Davis, California, USA.
16. Baksiene, E., Razukas, A., Repeekiene, J., Titova, J. (2014). Influence of different farming systems on the stability of low productivity soil in Southeast Lithuania. Zemdirbyste-Agriculture; 101(2):115-124
17. Befekadu T, Missiganaw W, Endeshaw A (2017). The traditional practice of farmers' legume-cereal cropping system and the role of microbes for soil fertility improvement in North Shoa, Ethiopia. Agricultural Research and Technology 13(4):1-6.
18. Belay Y (2015). Integrated soil fertility management for better crop production in Ethiopia. International Journal of Soil Science 10:1-16.
19. Berga L, Gebremedhin W, Terrisa J, Bereke-Tsehai T & Yaynu H (1994). Potato Improvement Research. In: Herath E & Lemma D (Eds.). Proceedings of the Second National Horticultural Workshop of Ethiopia. Addis Ababa, 1-3 December 1992, Institute of Agricultural Research and Food and Agriculture Organization, Addis Ababa, Ethiopia.
20. Berhe, G. T., Baartman, J. E. M., Veldwisch, G. J., Grum, B., & Ritsema, C. J. (2022). Irrigation development and management practices in Ethiopia: A systematic review on existing problems, sustainability issues, and future directions. *Agricultural Water Management*, *274*, 107959. https://doi.org/10.1016/j.agwat.2022.107959

21. Beyene, A., Cornelis, W., Verhoest, N.E., Tilahun, S., Alamirew, T., Adgo, E., De Pue, J., Nyssen, J., (2018). Estimating the actual evapotranspiration and deep percolation in irrigated soils of a tropical floodplain, North West Ethiopia. Agric. Water Manage, 202, 42–56.
22. Bhagwan SC, Soni AK, Khaswan SL (2012). Growth, yield, and quality of garlic (*Allium sativum* L.) as influenced by different nutrient management practices. Asian J. Agric. Res. 8:211-217.
23. Bodruzzaman, M., Meisner, C.A., Sadat, M.A. and Hossain, M.I. (2010). Long-Term Effects of Applied Organic Manures and Inorganic Fertilizers on Yield and Soil Fertility in a Heat-Rice Cropping Pattern. Brisbane, Australia.
24. Bot, A., and Benites, J. (2005). The importance of soil organic matter: Key to drought-resistant soil and sustained food production (No. 80). Food and Agriculture Organization.
25. Buzie-Fru, C. A. (2010). Development of a continuous single chamber vermicomposting toilet with urine diversion for on-site application.
26. CACC (Central Agricultural Census Commission). (2002). Report on the preliminary result of area, production, and yield of temporary crops (Meher season private peasant holdings). Part II. Ethiopian Agricultural Sample Enumeration, (2001/2002). Federal Democratic Republic of Ethiopia, Central Statistical Authority, Addis Ababa.
27. Campbell C A, Myers R J K & Curtin D (2004) Managing nitrogen for sustainable crop production. Earth Environ. Sci. 42: 277–296.
28. Cantwell M, Voss R, Hanson B, May D & Rice B 2006 Water and Fertilizer management for Garlic: Productivity, Nutrient and Water Use Efficiency, and Post-harvest Quality. Report of a FREP Contact No. 97–0207.
29. Central Statistical Agency CSA, (2011; 2012). The preliminary results of area, production, and yield of temporary crops. Statistical Bulletin, Volume 1, Addis Ababa, Ethiopia.
30. Central Statistical Agency. (2021). “The Federal Democratic Republic of Ethiopia Central Statistical Agency Agricultural Sample Survey,”
31. Chai, Q., Gan, Y., Zhao, C., Xu, H.L., Waskom, R.M., Niu, Y., Siddique, K.H., (2016). Regulated deficit irrigation for crop production under drought stress. A review. Agron. Sustain. Develop. 36 (1), 1–21
32. Chand, S., Anwar, M. and Patra, D.D. (2006). Influence of long-term application of organic and inorganic fertilizer to build up soil fertility and nutrient uptake in mint-mustard cropping sequence.Communication in Soil Science and Plant Analysis. 37: 63–76.
33. Chen, J.H. (2008).The Combined Use of Chemical and Organic Fertilizers and/or Biofertilizer for Crop Growth and Soil Fertility. Taichung, Taiwan.
34. Cheruth, A.J., Gopi, R., Sankar, B., Gomathinayagam, M., & Panneerselvam, R. (2008). Differential responses in water use efficiency in two varieties of Catharanthus roseus under drought stress. Comptes rendus, Biologies, 331(1), 42-47.
35. CSA (Central Statistical Agency) agricultural sample survey. (2017). Report on area and production of major crops (private peasant holdings, Meher season). Volume I, Statistical Bulletin, Addis Ababa, Ethiopia: 10-12.
36. CSA (Central Statistical Agency). (2010). Report on Farm Management Practices (Meher season private peasant holdings). Volume III, Part III. Ethiopian Agricultural Sample Survey, (2009/2010). Federal Democratic Republic of Ethiopia, Central Statistical Authority, Addis Ababa. Statistical Bulletin 468. Pp 10-19.
37. De Fraiture, C. and Perry, C. (2007). Why is agricultural water demand unresponsive at low price ranges Irrigation water pricing: The gap between theory and practice. 94-107.
38. Desta, Bizuayehu, Netsanet Tena, and Getachew Amare. (2021). “Growth and Bulb Yield of Garlic as Influenced by Clove Size.” The Scientific World Journal: 1–7.
39. Descheemaeker, K., S. W. Bunting, P. Bindraban, C. Muthuri, D. Molden, M. Beveridge, M. van Brakel, M. Herrero, F. Clement & E. Boelee, (2013). Increasing water productivity in agriculture. Managing Water Agroecosyst Food Secur 10:104.
40. Diacono, M., and Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. In Sustainable Agriculture Volume 2 (pp. 761-786). Springer, Dordrecht.

41. Diriba, Shiferaw, Nigussie Dechassa, Kebede Woldetsadik, Getachew Tabor and Sharma J. J., (2013). Growth, and Nutrient Content and Uptake of Garlic (Allium sativum L.) as Influenced by Different Types of Fertilizers and Soils. Science, Technology, and Arts Research Journal. Volume 2(3):35-50.
42. Diriba-Shiferaw, G. (2016). Review of management strategies of constraints in garlic (Allium sativum L.) production. Journal of Agricultural Sciences–Sri Lanka. 11(3).
43. Diriba-Shiferaw, G., Nigussie-Dechassa, R., Woldetsadik, K., Tabor, G., & Sharma, J. J. (2015). Effect of nitrogen, phosphorus, and sulfur fertilizers on growth yield, and economic returns of garlic (Allium sativum L.). *Science, Technology and Arts Research Journal*, *4*(2), 10-22.
44. Doran, J. W. and Parkin, T. B. (1994). Defining and assessing soil quality. Defining Soil Quality for a Sustainable Environment. Doran J W, Coleman D.C., Bezdicek, D.F. and Stewart, B. A. (Eds). SSSA Inc., Madison, Wisconsin, USA.
45. Doro, A.K., (2012). Effect of irrigation interval on the Yield of Garlic (Allium sativum L.) at Ajiwa irrigation site of Katsina State-Nigeria. J. Res. Nat. Develop. 10 (2), 30–33.
46. Dutta, S., Pal, R., Chakeraborty, A. and Chakrabarti, K. (2003). Influence of integrated plant nutrient supply system on soil quality restoration in red and laterite soil. Archives of Agronomy and Soil Science, 49: 631–637.
47. Ebrahimi, E., Werren, D., und Niemsdorff, P. V. F. (2018). Suppressive effect of composts from residual biomass on Pythium ultimum. Journal of Plant Diseases and Protection; 125(5):443-449.
48. Elkholy, M.M., Samira, E., Mahrous and El-Tohamy, S.A. (2010). Integrated Effect of Mineral, Compost and Biofertilizers on Soil Fertility and Tested Crops Productivity. Research Journal of Agriculture and Biological Sciences, 5, 453-465.
49. Fageria, N. K. (2012). Role of soil organic matter in maintaining sustainability of cropping systems. Communications in Soil Science and Plant Analysis; 43(16):2063-2113.
50. Fairhurst, T. (20120. Handbook for integrated soil fertility management. Technical Centre for Agricultural and Rural Cooperation.
51. Fanish, S.A., (2013). Influence of drip fertigation on water productivity and profitability of maize. Afr. J. Agric. 8 (28), 3757–3763.
52. FAO (2019) (Food, Agriculture Organization of the United Nations), (9010). FAOSTAT Production Statistics. FAO, Rome, Italy
53. FAO (Food and Agricultural Organization). (2011). The state of the world's land and water resources for food and agriculture - Managing systems at risk. FAO, Rome and Earthscan, London
54. FAO (Food and Agriculture Organization). (2003). Global review of area and production of garlic, Pp 135-139.
55. FAO. (2004). The market for non-traditional agricultural exports. FAO commodities and trade technical paper 3.
56. FAO. (2006a). World agriculture: towards 2030/2050 – Interim report. Rome.
57. FAO. "Food and Agriculture Statistics." (2023). Food and Agriculture Organization of the United Nations. Accessed May 5, 2023.
58. FAOSTAT (Food and Agriculture Organization of the United Nations Statistics). (2011).
59. Figliuolo, G., Candido, V., Logozzo, G., Miccolis, V. and Spagnoletti, P. (2001). Genetic evaluation of cultivated garlic germplasm (Allium sativum L. and A. ampeloprasum L.). Euphytica, 121 (3): 325-334.
60. Fijakowski, K., Kacprzak, M., Grobelak, A., Placek, A. (2012). The influence of selected soil parameters on the mobility of heavy metals in soils. 15, 81-92.
61. Foissy, D. Vian, J. F., David, C. (2013). Managing nutrient in organic farming system: reliance on livestock production for nutrient management of arable farmland. Organic agriculture; 3(3-4):183-199.
62. Friesen N, Fritsch RM, Blattner FR. (2006). Phylogeny and new intrageneric classification of Allium L. (Alliaceae) based on nuclear ribosomal DNA sequences. Aliso.
63. Gebrehiwot, K. A. & M. G. Gebrewahid, 2016. The need for agricultural water management in sub-Saharan Africa. *Journal of Water Resource and Protection* 8(09):835.395.
64. Gebremeskel, Teklay Berhe., Jantiene, E.M. Baartman., Gert Jan, Veldwisch., Berhane, Grum., Coen, J. Ritsema., (2022). Irrigation development and management practices in Ethiopia: A systematic review on

existing problems, sustainability issues, and future directions. Agric. *Water Manage*., 274, 107959. 1–13.22:372.

65. Getachew, T. and Asfaw Z. (2000). Research achievements in garlic and shallot. Research Report. No. 36. Ethiopian Agricultural Research Organization, Addis Ababa. Ethiopia.
66. Goldy, R. (2000). Producing garlic in Michigan, southwest Michigan Research & Extension Center. Extension bulletin e-2722. Michigan State University.
67. Gonzalez de Andres, E., Seely, B., Blanco, J. A., Imbert, J. B., Lo, Y. H., & Castillo, F. J. (2017). Increased complementarity in water--limited environments in Scots pine and European beech mixtures under climate change. *Ecohydrology*, *10*(2), e1810.
68. GTP (Growth and Transformation Plan). (2010). The Federal Democratic Republic of Ethiopia five-year Growth and Transformation Plan, 2010/11-2014/15, Sep. 2010, Addis Ababa, Ethiopia.
69. GTZ (2009) Food Crisis and Land: The World Food Crisis, Land Degradation and Sustainable Land Management: Linkages, Opportunities and Constraints.
70. Gubb I R & Tavis M S H (2002). Onion preharvest and postharvest considerations. In: Rabinowitch H D & Currah L (Eds.) (pp.237–250). Allim Crop Science, CABI Publishing, UK.
71. Habtu, S., Erkossa, T., Froebrich, J., Tquabo, F., Fissehaye, D., Kidanemariam, T., Xueliang, C., (2020). Integrating participatory data acquisition and modeling of irrigation strategies to enhance water productivity in a small-scale irrigation scheme in Tigray, Ethiopia. Irrig.
72. Hamma I L, Ibrahim U & Mohammed A B (2013). Growth, yield and economic performance of garlic (Allium sativum L.) as influenced by farm yard manure and spacing in Zaria, Nigeria. *J. Agril. Econ. Dev*. 2: 1–5.
73. Han, S.H., Hwang, J.Y., Kim, J., S.B. and Park, B.B. (2016). The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. Forest Science and Technology, 12: 137-143.
74. Hanks, R.J., (1974). Model for predicting plant yield as influenced by water use. Agron. J. 66, 660–664.
75. Hanks, R.J., Gardner, H.R., Florian, R.L., (1969). Plant growth-evapotranspiration relations for several crops in the Central Great Plains. Agron. J. 61.1, 30–34.
76. Hanson, B., May, D., Voss, R., Cantwell, M. and Rice, R. (2003). Response of garlic to irrigation water. Agricultural water management, 58(1): 29-43.
77. Harendra S, Kumar S M & Singh K V (2009). Effect of sulfur and FYM on yield and nutrients uptake by garlic (*Allium sativum* L.) in alluvial soil. Ann. Hort. 2: 86–88.
78. Hartemink, A.E. (2006). Soil Fertility Decline: Definitions and Assessment. In: Encyclopedia of Soil Science, *Taylor and Francis*, New York, 1618-1621.
79. Hassan A H 2015 Improving growth and productivity of two garlic cultivars (Allium sativum L.) grown under sandy soil conditions. *Middle East J. Agri. Res*. 4: 332–346.
80. Hector, S., Espino F. San J. H., Olivio H. H., (2012). Agronomic and Biotechnological Strategies for Breeding Cultivated Garlic in Mexico, Prof. Mahmut Caliskan (Ed.), Genetic D Anand, M., Sankari, A., & Anita, B. (2017). Influence of integrated nutrient management for garlic under Nilgiris condition. *International Journal of Current Microbiology and Applied Sciences*, *6*(12), 3833-3838.
81. Henao, J., & Baanante, C. 1999. Estimating rates of nutrient depletion in soils of agricultural lands Shock, C.C., Feibert, E.B.G., & Saunders, L.D. (1998). Onion yield and quality affected by soil water potential as irrigation threshold. HortScience, 33, 1188-1191.
82. Hickey, M. (2012). *Growing garlic in NSW*. New South Wales. Department of Primary Industries.
83. Hintsa Meresa, Zelalem Mengistu, Misene Bisetegn. (2016). Effects of Integrated Soil Fertility Management on Sustainable Crop Production. *Journal of Economics and Sustainable Development*; 7(1): 25-30.
84. Hussain, I., Ahsan, M., Saleem, M., Ahmad, A., 2009. Gene action studies for agronomic traits in maize under normal and water stress conditions. Pak. J. Agri. Sci 46 (2), 107–112.
85. Ibrawuchi, I.I., Opara, F.A., Tom, C.T Obiefuna, J.C. (2007). Graded replacement of inorganic with organic manure for sustainable maize production in Owerri Imo State, *Nigeria. Life Science Journal;* 4 (2): 82-87.

86. IFAD (International Fund for Agricultural Development), (2005). Special country program phase II. Interim evaluation report number 1643-ET, Ethiopia IFAD (International Fund for Agricultural Development).
87. Incrocci, L., Marzialetti, P., Incrocci, G., Di Vita, A., Balendonck, J., Bibbiani, C., Spagnol, S. and Pardossi, A. (2014). Substrate water status and evapotranspiration irrigation scheduling in heterogeneous container nursery crops. Agricultural Water Management. 131: 30-40.
88. Ipek, M., Ipek S. and Simon P., (2003). Comparison of AFLPs, RAPD markers, and isozymes for diversity assessment of garlic and detection of putative duplicates in germplasm collections. *Journal of American Society for Horticultural Science,* 128: 246-252
89. Ipek, M., Ipek, S. Almquist G. and Simon P., (2005). Demonstration of linkage and development of the first low-density genetic map of garlic, based on AFLP markers. *Theoretical and Applied Genetics,* 110:228-236.
90. IWMI (International Water Management Institute). (2010). Irrigation potential in Ethiopia; Constraints and opportunities for enhancing the system.
91. Jackson, M. L., (1958). Soil chemical analysis. Practice Hall of India, Volume 9: Pp. 488-521 New Delhi.
92. Jaleel, C.A., Manivannan, P., Sankar, B., Kishorekumar, A., Gopi, R., Somasundaram, R., & Panneerselvam, R. (2007). Water deficit stress mitigation by calcium chloride in Catharanthus roseus; effects on oxidative stress, proline metabolism, and indole alkaloid accumulation. Colloids Surf. B: Biointerfaces, 60, 110–116.
93. James, R., James, R. R., & Pitts-Singer, T. L. (Eds.). (2008). *Bee pollination in agricultural ecosystems*. Oxford University Press on Demand.
94. Jarvan, M., Vettik, R., Tamm, K. (2017). The importance and profitability of farmyard manure application to an organically managed crop rotation. Zemdirbyste Agriculture; 104(4).
95. Jiang, Wenshun, Kongjun Wang, Qiuping Wu, Shuting Dong, Peng Liu, and Jiwang Zhang. “Effects of narrow plant spacing on root distribution and physiological nitrogen use efficiency in summer maize.” *The Crop Journal* 1, no. 1 (2013): 77-83.
96. Jo MH, Ham I, Moe KT, Kwon SW, Lu FH, Park YJ, Kim WS, Won MK, Kim T, Lee EM (2012). Classification of genetic variation in garlic (*Allium sativum* L.) using SSR markers. Aust J Crop Sci 6:25–631
97. Jones, M.G, Hughes J., Tregova A., Milne J., Tomsett A.B., Collin H.A. (2004). Biosynthesis of the flavor precursors of onion and garlic”. *Journal of Experimental Botany*. 55 (404):1903- 1918.
98. Josling PA (2005). The heart of garlic Nature’s aid to healing the human body, HEC Publishing, Chicago Illinois. pp 20
99. Kamenetsky, R. and Rabinowitch H. (2001). Floral development in bolting garlic. Sex and plant Reproduction, 4: 235-241.
100. Kamenetsky, R., Shafir, I. L., Zemah, H., Barzilay, A., & Rabinowitch, H. D. (2004). Environmental control of garlic growth and florogenesis. *Journal of the American Society for Horticultural Science*, *129*(2), 144-151.
101. Karlen, D., Andrews, S., Wienhold, B. and Obeck, T. (2008). Soil Quality Assessment: Past, Present and Future. *Journal of Integrative Bioscience*, 6, 3-14.
102. Kassa, B., & Alemu, D. (2016). Agricultural research and extension linkages: Challenges and intervention options. *Ethiopian Journal of Agricultural Sciences*, *27*(1), 55-76.
103. Kilgori, M., MagaJi M. and Yakubu A. (200 a). Effect of plant spacing and date of planting on yield of two garlic (*Allium Sativum* L.) cultivars in Sokoto, Nigeria. *American-Eurasian Journal of Agricultural & Environmental Science,* 2(2): 153-157.
104. Kudi, T.M1., Banta, A. L2., Akpoko, J.G 1. and Wayne, D1. (2008). Economic Analysis of Garlic Production in Bebeji Local Government Area of Kano State, Nigeria. *Ozean Journal of Applied Sciences*.
105. Lemma D & Herath E (1994) Agronomic studies on Allium. In: Horticultural research and development in Ethiopia (pp.139–145), 1–3 December 1992, Institute of Agricultural Research and Food and Agricultural Organization. Addis Ababa, Ethiopia.
106. Mansell P, Reckless J. (1991). Effects on serum lipids, blood pressure, coagulation, platelet aggregation, and vasodilation. BMJ. 303:379- 380.
107. Marschner H (1995). Mineral nutrition of higher plants. 2nd Edition. Academic Press, London, Harcourt Brace and Company, pp.889.
108. McLaurin, W. J., Adams D. and Eaker T., (2012). Garlic Production for the Gardener. Learning for life. Circular 854: Pp.1-7.

109. Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue, and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, *15*(5), 1577-1600.
110. Mengesha, Worku and Tesfaye Azane (2015). Effect of Spacing in Incidence and Severity of Garlic Rust (*Puccinia Allii* (Rudolphi.) and Bulb Yield and Related Traits of Garlic at Eastern Ethiopia. *Journal of Plant Pathology and Microbiology*, 6 (10): 314. *doi:10.4172/2157- 7471.100031*
111. Metasebia, M. and Shimelis H. (1998). Proceeding of the 15th Annual Research and Extension Review Meeting, Alemaya Research Centre. Alemaya University of Agriculture. Pp. 216-235.
112. Molden, D., (2003). A water-productivity framework for understanding and action. In: Kijne, J.W., Barker, R., Molden, D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. International Water Management Institute, Colombo, Sri Lanka, pp. 1–18.
113. Molden, D., Oweis, T., Steduto, P., Bindraban, Hanjra, M.A. and Kijne J. (2010). Improving agricultural water productivity: Between optimism and caution. Agricultural Water Management. 97(4): 528-535.
114. Mulatu, A., Tesfaye, B., & Getachew, E. (2014). Growth and bulb yield garlic varieties affected by nitrogen and phosphorus application at Mesqan Woreda, South Central Ethiopia. *Sky Journal of Agricultural Research*, 3, 249–255.
115. Mungai, N.W., Bationo, A. and Waswa, B. (2009). Soil Properties as Influenced by Soil Fertility Management in Small Scale Maize Farms in Njoro, Kenya. *Journal of Agronomy*, 4, 131-136.
116. Negassa, W., Getaneh, F., Deressa, A. and Dinsa, B. (2007) Integrated Use of Organic and Inorganic Fertilizers for Maize Production. Witzenhausen, Germany.
117. Nonnecke, I.L. 1989. Vegetable Production, New York. 657p.
118. Nyalemegbe, K.K., Oteng, J.W. and Brempong, S.A. (2009). Integrated Organic-Inorganic Fertilizer Management for Rice Production on the Vertisols of the Accra Plains of Ghana. *West Africa Journal of Applied Ecology*, 16, 23-33.
119. Oki, T. and Kanae, S. (2006). Global hydrological cycles and world water resources. science. 313(5790): 1068-1072.
120. Olsen, S., Cole C., Watanabe F. and Dean L. (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA, Circular 939: 1-19.
121. Palm, C. A., Myers, R. J., & Nandwa, S. M. (1997). Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. *Replenishing soil fertility in Africa*, *51*, 193-217.
122. Parekh J, Chanda S. (2007). In vitro antimicrobial activity of Trapa natans L. Fruit rind e Potgieter J 2006 Verbal communication on macro elements application time. Researcher, Limpopo Department of Agriculture, April 2006.
123. Qiong, S.u., Vijay, P.S., Karthikeyan, R., (2022). Improved reference evapotranspiration methods for regional irrigation water demand estimation. Agric. Water Manage. 274, 1–15.
124. Quansah, G.W. (2010). Effect of Organic and Inorganic Fertilizers and Their Combinations on the Growth and Yield of Maize in the Semi-Deciduous Forest Zone of Ghana. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
125. Rao M R, Kwesiga N A, Duguma F B, Frazel S, Jama B & Buresh R. (1998). Soil fertility Replenishment in Sub-Saharan Africa. In: Agroforestry today (Debra London Ed.) International Center for Research in Agroforestry (ICRAF) UK. 10: 2 –5.
126. Rice R P, Rice L W & Tindall H D (1990). Fruits and vegetable production in warm climates. Macmillan Education Ltd. Hong Kong, pp.486.
127. Ryan J (2008). A Perspective on balanced fertilization in the Mediterranean Region. Turk J. Agri. For. 32: 79–89.
128. Ryu, J. H., & Kang, D. (2017). Physicochemical properties, biological activity, health benefits, and general limitations of aged black garlic: A review. *Molecules*, 22(6), 919.
129. SAS, Institute Inc., (2007). SAS/STAT User's Guide, SAS Online document 9.1.3, Cary, NC: SAS Institute, Inc.
130. Seleshi, Y. and Zanke, U. (2004). Recent changes in rainfall and rainy days in Ethiopia. International Journal of Climatology: A Journal of the Royal Meteorological Society. 24(8): 973-983.

131. Sezen, S. M., Yucel, S., Tekin, S., & Yıldız, M. (2019). Determination of optimum irrigation and effect of deficit irrigation strategies on yield and disease rate of peanut irrigated with drip system in Eastern Mediterranean. *Agricultural Water Management*, *221*, 211-219.
132. Shalini, S. B., Channal, H. T., Hebsur, N. S., Dharmatti, P.R. and Sarangamath, P.A. 2002. Effect of integrated nitrogen management on nutrient uptake in Knolkhol, yield and nutrient availability in the soil. *J. Karanataka Agril. Sci*.15 (1): 43-46.
133. Shege, Getu Yayeh, Alemayehu Melkamu, Haileslassie Amare, and Dessalegn Yigzaw (2021) "Assessment of Small Holder Farmers Garlic (Allium Sativum L.) Production Practices under Irrigated Farming System in the Highlands of Ethiopia." African Journal of Agricultural Research.17(9): 1172–79.
134. Shivananda IT (2002). Integrated nutrient management on physical conditions, soil fertility, and productivity of crops in dry land vertisol. Karnataka Journal of Agricultural Sciences 15(1):186-187.
135. Silabut, N., Naruka, I.S., Shaktawat, R.P.S., Verma, K.S., and Azeze S. (2014). Response of garlic cultivars to irrigation levels. Indian Journal of Horticulture. 71(3): 354-359.
136. Singh, P., et al., (2010). Response of garlic (Allium sativum) cultivars to different dates of sowing in Malwa region of Madhya Pradesh. Indian Journal of Agricultural Sciences. 80(7): 645-648
137. Singh, Y. and R. Chand. (2003). Performance studies of some garlic (Allium sativum L.) clones. Himachal J. Agri. Res. 29(1&2): 35-42.
138. Steduto, P., Hsiao, T.C., Fereres, E., Raes, D., (2012). Crop yield response to water, vol. 1028. Food and Agriculture Organization of the United Nations, Rome.
139. Suleria, H. A. R., Butt, M. S., Khalid, N., Sultan, S., Raza, A., Aleem, M., & Abbas, M. 2015. Garlic (Allium sativum): diet-based therapy of 21st century–a review. *Asian Pacific journal of tropical disease*, *5*(4), 271-278.
140. Teshome, Y., B. Biazin, K. Wolka & A. Burka, 2018. Evaluating performance of traditional surface irrigation techniques in Cheleleka watershed in Central Rift Valley, Ethiopia. Applied Water Science 8(8):219 doi:10.1007/s13201-018- 0862-z.
141. Thangasamy, A. and Lawande, K.E. (2015). Integrated nutrients management for sustainable onion production. *Indian Journal of Horticulture*, 72: 347-352.
142. Tilahun H, Teklu E, Michael M, Fitsum H & Awulachew S B (2011). Comparative performance of irrigated and rain-fed agriculture in Ethiopia. *World Appl. Sci. J.* 14: 235–244.
143. Tindal, H. D., (1986). Vegetable in the Tropics. Macmillan Education Limited, Houdmills.
144. Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpeh, O., Pypers, P., Tabo, R., Shepherd, K., Smaling, E. and Woomer, P. (2010). Integrated Soil Fertility Management: Operational Definition and Consequences for Implementation and Dissemination. Outlook on Agriculture, 39, 17-24.
145. Verma, S., Choudhary, M. R., Yadav, B. L. and Jakhar, M. L. (2013). Influence of vermicompost and sulfur on growth and yield of garlic (*Allium sativum* L.) under semi-arid climate. Department of Horticulture, S.K.N. College of Agric. Rajasthan, *India. J. of spices and aromatic crops* 22 (1): 20–23.
146. Voigt, C. (2004). Glorious garlic herb of the year 2004. *Journal of International Herb*, Pp. 1-6. Association Horticulture Committee, Virginia State University.
147. Walkley, A. and Black C. (1934). Determination of organic matter in the soil by chronic acid digestion. *Journal of Soil Science*, 63:251-264.
148. Wang, Y., Liu, F., Jensen, C.R., (2012). Comparative effects of deficit irrigation and alternate partial root-zone irrigation on xylem pH, ABA, and ionic concentrations in tomatoes. J. Exp. Bot. 63 (5), 1907–1917.
149. Worku, S., Merse, M., Gebrehana, G., Tesfaye, F., & Tejada Moral, M. (2018). Response of garlic (Allium sativum L.) to nitrogen and phosphorus under irrigation in Lasta district of Amhara Region, Ethiopia. Cogent Food & Agriculture, 4(1), 1532862.
150. Yayeh, S.G., Melkamu, A., Amare, H. and Yigzaw, D. (2017). Economic and agronomic optimum rates of NPS fertilizer for irrigated garlic (Allium sativum L) production in the highlands of Ethiopia. Cogent Food & Agriculture 3(1):1333666.
151. Yohannes U (1994). The effect of nitrogen, phosphorous, potassium, and sulfur on the yield and yield components of Enset (*Ensete ventricosum* W.) in southeast Ethiopia. Doctoral dissertation. Institute of Plant Nutrition, Faculty of Agriculture. Justus Liebig University, Giessen, Germany.

doi:10.20944/preprints202511.0102.v1

152. Zerssa, G., Feyssa, D., Kim, D.-G., & Eichler-Löbermann, B. (2021). Challenges of Smallholder Farming in Ethiopia and Opportunities by Adopting Climate-Smart Agriculture. *Agriculture*, *11*(3), 192. https://doi.org/10.3390/agriculture11030192