# RESPONSE OF WHEAT (*Triticum aestivum* L.) TO PHOSPHORUS AND POTASSIUM FERTILIZERS RATES AT KECHI, SOUTH WEST ETHIOPIA

**M.Sc. THESIS**

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**HAWASSA UNIVERSITY**
**COLLEGE OF AGRICULTURE**
**HAWASSA, ETHIOPIA**

**OCTOBER, 2024**
**HAWASSA, ETHIOPIA**

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**A THESIS SUBMITTED TO THE SCHOOL OF PLANT AND HORTICULTURAL SCIENCES, COLLEGE OF AGRICULTURE, SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN PLANT SCIENCE**
**(SPECIALIZATION: AGRONOMY)**

**HAWASSA, UNIVERSITY**
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**OCTOBER, 2024**

**COLLEGE OF AGRICULTURE**
**SCHOOL OF PLANT AND HORTICULTURAL SCIENCES**
**ADVISORS' APPROVAL SHEET-1**
**HAWASSA UNIVERSITY (Submission sheet-1)**

This is to certify that the thesis entitled "**Response of Wheat (*Triticum aestivum* L.) To Phosphorus and Potassium Fertilizer Rates at Kechi, South West Ethiopia**", submitted in partial fulfillment of requirements for the degree Master of Science in Plant Science with specialization in **Agronomy** to Graduate program of the **School of Plant and Horticultural Sciences**, College of Agriculture, is a record of original research carried out by **Andualem Bezula Feleho** ID. No **GP Agro R/0003/15**, under our supervision, and no part of the thesis has been submitted for any other degree or diploma.

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

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| Name of Major Advisor | Signature | Date |
| | OR | |
| Name of co-advisor | Signature | Date |

## EXAMINERS' APPROVAL SHEET

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**(Submission Sheet-2)**

We, the undersigned members of the Board of Examiners of the final open defense by **Andualem Bezula Feleho** have read and evaluated his thesis entitled **"Response of Wheat (*Triticum aestivum* L.) To Phosphorus and Potassium Fertilizer Rates at Kechi, South West Ethiopia**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree of Master of Science in Plant Sciences with a specialization in Agronomy.

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Final approval and acceptance of the thesis are contingent upon the submission of the final copy of the thesis to the School of Graduate Studies (SGS) through the school of Graduate Committee (SGC) of the candidate's department.

Stamp of SGS Date

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## DEDICATION

I dedicate this thesis to my lovely family, who support me in my success. It is my hope and prayer my brothers will became academic giants

# STATEMENT OF AUTHOR

First, I declare that this thesis is my effort and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for a M.Sc. degree at the Hawassa University and is deposited at the university library to be made available to borrowers under rules of the library. I sincerely declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this thesis are allowable without special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

Name: **Andualem Bezula Feleho** Signature: _____________ Date: _______________

Place: College of Agriculture, Hawassa University, Hawassa

Date of submission: ____/____/________

## LIST OF ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| CEC | Cation Exchange Capacity |
| CIMMYT | International Maize and Wheat Improvement Center |
| CSA | Central Statistical Agency |
| FAO | Food and Agriculture Organization |
| FAOSTAT | Food and Agriculture Organization of the United Nations Statistics |
| KCl | Potassium Chloride |
| LSD | Least Significance Difference |
| MOA | Ministry of Agriculture |
| RCBD | Randomized Complete Block Design |
| SAS | Statistical Analysis System |
| SSA | Sub-Sahara Africa |
| SWEPR | South West Ethiopia People Region |
| TSP | Triple Super Phosphate |
| USDA | United States Department of Agriculture |

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**RESPONSE OF WHEAT (*Triticum aestivum* L.) TO PHOSPHORUS AND POTASSIUM FERTILIZERS RATES AT KECHI, SOUTH WEST ETHIOPIA**

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## *ABSTRACT*

*Wheat is the most significant cereal and staple crop. However, the primary obstacles to output and productivity are the depletion of soil nutrients and the improper application of fertilizers. Therefore, this experiment was conducted at Kechi, South West Ethiopia, to evaluate the growth and yield response of wheat to phosphorus and potassium fertilizer application rates during the 2023 main cropping season. The experiment comprised 12 treatment combinations with four rates of phosphorus (P) (0, 10, 20, and 30 kg/ha) and three rates of potassium (K) (0, 30, and 60 kg/ha) in the form of triple superphosphate (TSP) and murate of potash (KCl), respectively. The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times per treatment. Data were collected on crop phenology, growth, yield, and yield components. The collected data were analyzed using statistical analysis software version 9.2.The outcome showed that the primary effects of potassium and phosphorus had a considerable effect on the harvest index and the number of productive tillers. The interaction effect of phosphorus and potassium had a substantial effect on the following parameters: days to heading, days to physiological maturity, plant height, and total tiller number, number of grains per spike, thousand seed weight, aboveground biomass, grain yield, and straw yield. Furthermore, 20 kg/ha P and 30 kg/ha K fertilizer application rates provided the maximum grain production (4350 kg/ha). The economic analysis also indicates that a net benefit of 229,815 ETB/ha and a marginal rate of return of 1783.1% were achieved from 20 kg/ha P and 30 kg/ha K combination. As a result, this combination can be suggested to raise wheat's grain production. However, since this experiment was conducted in a single season and at one site, repeating over seasons and locations will be required to come up with a plausible recommendation.*

**Keywords:** Crop phenology, Fertilizer, Growth, Wheat seed

# 1. INTRODUCTION

The world wheat production reaches about 776.5 million tons in 2020, also estimated and forecasted to be 778.3 and 770.3 million tons by 2021 and 2022, respectively (FAO,2022). Wheat is the second largest grain crop worldwide in acreage and second total production volume. The global production volume of wheat came to almost 785 million metric tons in the marketing year of 2023/24 (Schroeder, 2021). This was a decrease of about four million tons compared to the previous year. Wheat is not only the most important food security crop but also it is currently becoming strategic as a cash crop at the global level (Langridge et al., 2022).

Wheat (*Triticum aestivum* L.) (Triticum aestivum, 2n = 6x = 42, AABBDD) is an important staple food crop in Ethiopia, especially in urban areas. It is a staple food in the diets of several Ethiopian, providing about 15 percent of the caloric intake for the country's over 90 million population (FAO, 2015a), placing it second after maize and slightly ahead of teff, sorghum, and enset, which contribute 10-12 percent each (Minot *et al*., 2015). After South Africa, Ethiopia is the second largest wheat producer in Sub-Saharan Africa (FAO, 2022). It is used for making bread, biscuit and pastry products, and also for the production of starch and gluten.

Wheat is one of the most important food security crops in Ethiopia. It is cultivated on a total area of 2.1 million (1.7 million ha rain fed and 0.4 million ha irrigated) hectares annually with a total production of 6.7 million tons of grain at an average productivity of 3.0 and 4.0 t/ha under rain-fed and irrigated conditions, respectively during 2021/22 (Tadesse, *et al*., 2022) Wheat ranks second next to maize in terms of yield production (5,780,130.596 tons) and third in terms of area coverage (1,897,405.05 hectares) following teff and maize among cereals for rain fed production in Ethiopia (CSA, 2022).Wheat is commonly grown at an altitude ranging from 1500 to 3000 meters above sea level, between 6-15º N latitude and 35-42ºE longitude in Ethiopia (Tirfi *et al*., 2022). The major wheat producing areas in Ethiopia are located in Oromia region (Arsi, Bale, Shewa, Wolega, Jimma zone, in Amhara region (North, south and central Gondar zone, North Shewa and Awi) in Southern Nations Nationalities & Peoples Region (Guraghe, Hadiya, Kembata tembaro, Wolaita, Keffa, Gamo-Gofa, Silte and Halaba), Tigray region, Benishangul Gumuz region and Afar region (CSA, 2021).

Soil degradation and depletion of soil nutrients are among the major factors threatening sustainable cereal production in the Ethiopian highlands (Aleminew and Alemayehu, 2020). In line with this, low production of wheat has been shown in various parts of the country as a result of limited nutrient supply (Gebreselassie, 2002). As Taye and Yifru (2010) indicated, land degradation is the major one because of great deforestation, human and livestock population pressure, inadequate use of crop residue and animal dung and little or no use of modern technologies to restore soil fertility. In Ethiopia; the major challenges facing agriculture are low productivity, low use of improved farm inputs, and dependency on traditional farming and rain fall. As a result, food insecurity and poverty are prevalent in the country (Belay et al., 2024).

Phosphorous (P) is one of most limiting plant nutrients in the tropics (Mardamootoo *et al.*, 2021). Phosphorous required in the early stages of growth (Grant *et al*., 2001) necessary for many plant processes including synthesis of phospholipids, energy transfer, and enzyme activation (Hawkes ford, 2012) for optimum crop production. Inadequate availability is a major limitation to plant growth and development (Schacht man *et al*., 1998) and consequently global crop production (Raghothama and Karthikeyan, 2005). It is usually the most yields limiting of soil supplied elements, and soil P tends to decline when soils are used for agriculture (David and David, 2012. It is estimated that 30–40% of global agricultural soils are limited by P availability and it is second only to nitrogen (N) in limiting agricultural productivity (Vance *et al*., 2003). Heavy rains during main cropping season cause substantial nutrient losses due to intense leaching and erosion on Nitosols (Woldeab *et al*., 1991). Phosphorous is deficient in about 70% of the soils in Ethiopia (Mamo, and Haque, 1991). One of major constraints that are responsible for low yield of wheat crop is P deficiency (Balesh *et al*., 2005).

Continuous cropping, in which fertilizer responsive varieties and improved management practices results in K mining from the soil. Wheat crops can remove more than 400 kg $K_2O$ $ha^{-1}year^{-1}$ (Hailu *et al.*, 2017). The total absence or low application level of K fertilization combined with intensive continuous cropping leads to the depletion of soil K reserves. Even soils which are initially well supplied with K will become deficient under such management systems.

Total consumption of K from soil by wheat producing yields of 10 t $ha^{-1}$ varies from 160 to 242 kg K $ha^{-1}$ (Kemmler, 1983). The risk of yield decline can be minimized by application of mineral fertilization balanced in terms of all nutrient elements (Öborn *et al*., 2005). The influence of P and K is mainly an aggregate of the functions played by nutrients in mitigating negative effects of biotic and abiotic stresses. Plants provided with sufficient amounts of P and K are less vulnerable to water deficiency, low temperatures and pathogen attacks (Ma *et al*., 2006). Potassium and phosphorus yield-stimulating functions are different, which stems from their differentiated influence on the plant growth during the vegetation period.

In addressing this issue, balanced fertilization with an optimum application rate is necessary to improve soil fertility and thus increasing the productivity of crops including wheat. Poor soil fertility especially low availability of nitrogen (N) and phosphorus (P) has been demonstrated to be a major constraint to wheat production in Ethiopia (Aleminew and Alemayehu, 2020) and (Mamo et al., 1988). Other studies in Ethiopia showed deficient soil K levels (Mamo and Haque, 1988; Gebeyehu and Mamo, 1999; Bellete, 2014; Mekonnen, 2014; EthioSIS, 2015; Laekemariam, 2015). In addition limitation of Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur (S), Zinc (Zn), Boron (B) and Iron (Fe) on the soil of the former SNNPR were reported (EthioSIS, 2016).

Despite the significant area of wheat production in Ethiopia, the average productivity of wheat at national level, the former South Nations Nationalities and People Regional State (SNNPRS) and Dawro Zone is 2.67, 2.58, 1.45 ton ha-1, respectively (CSA, 2021).

South-West Ethiopia's Kechi Woreda, in the Dawro Zone, is home to Kechi Research Farm. Farmers have long owned it, using intensive and inadequate management techniques, and the region receives a lot of rain each year. Additionally, a preliminary evaluation of the farm revealed nutritional limitations for N, P, S, and B. Furthermore, the soil reaction was highly acidic (pH less than 5.5). Crop residue clearance, basic ion leaching (Ca+2, Mg+2, K+, Na+), and inadequate soil management techniques can all contribute to this. Thus, increasing wheat output and productivity on a sustainable basis depends critically on reaching the ideal pH and nutrient levels in the soil.

The impact of P and K rates on wheat plant yields has not been thoroughly studied. According to a study done in the Kokate, Wolaita area, applying 150 kg NPS $ha^{-1}$ and 50 kilogram KCl $ha^{-1}$ increased wheat output (Tesfay *et al*., 2021). To provide the ideal P and K fertilizer rates, more research is necessary. The purpose of this study is to ascertain the optimal degree of P and K fertilization for wheat development, yield components, and yield, at the Wolaita Sodo University research farm site, Kechi, located in the Dawro zone in South West Ethiopia.

Therefore, this experiment was designed with the following objectives:

Objectives:

- To evaluate the growth and yield response of wheat to P and K fertilizers rates at Kechi during 2023 main cropping season.
- To determine the optimum combination rates of P and K fertilizer for optimal wheat crop production at Kechi during 2023 main cropping season.
- To determine the economic feasibility of various phosphorus(P) and potassium (K) fertilizer rate for optimal wheat crop production at Kechi during 2023 main cropping season.

# 2. LITRATURE REVIEW

## 2.1. Origin and Taxonomy of Wheat

According to the earliest historic records, wheat was an important cultivated cereal in south-western Asia, its geographical center of origin. Many wild species of Triticum are found in Lebanon, Syria, Northern Israel, Iraq, and Eastern Turkey. Wheat was cultivated in ancient Greece and Egypt in prehistoric times. The central Asia, Near East Mediterranean, and Ethiopian regions are the world's most important centers of diversity of wheat and its related species (Kundu and Nagarajan, 1996). Bread wheat arose farther northwest, away from the Fertile Crescent, in the corridor extending from Armenia in Transcaucasia to the southwest coastal areas of the Caspian Sea in Iran (Dvorak *et al*., 1998). In this region, Ae. tauschii var. strangulata is predominant, which evidently hybridized with cultivated emmer to produce *T. aestivum*. In a recent study, Wang et al. (2013) genotyped using single nucleotide polymorphism (SNP) markers 477Ae. tauschii and wheat accessions collected from eastern Turkey to China. Wheat is grown in most temperate and subtropical countries and in many tropical countries (Peterson, 1965).

The majority of the cultivated wheat varieties belong to three main species of the genus Triticum. These are the hexaploid, T. aestivum L (bread wheat), the tetraploid, T. durum, and the diploid, T. dicoccum. Schrak and T. monococcum. Globally, *T. aestivum* is the most important species, which covers 90 percent of the area under wheat cultivation. The second most popular wheat is durum wheat, which covered about 9 percent of the total area, while T. diccous and T. monococcum cover less than 1 percent of the total area (Shashikale, 2006). In Ethiopia, all three main species of the genus Triticum are found. From this, *T. aestivem* is produced in most parts of the country, while T. durum and T. dicoccum are small in their area coverage. Both wild and cultivated Triticum genera belong to the family Gramineae, the grass family. Triticum is only one of some 600 genera belonging to this family, which itself comprises over 5000 species (Peterson, 1965).

## 2.2. Importance of Wheat

As one of the main cereal crops grown in Ethiopia today, wheat influences food preferences and dietary customs and is a significant source of protein and energy for the people living in the country's highlands. Furthermore, in order to achieve national food self-sufficiency, wheat has been chosen as one of the target crops. With the greatest crop area dedicated to it and the highest yield of any crop, wheat is one of the most abundant food crops in the world and provides the world's population with both energy and protein. Increasing wheat production is crucial for ensuring food security (Chhokar *et al*., 2006). Bread wheat flour is used to manufacture Arabic bread, French bread, chapatti, cookies, and pastries.

Wheat has played a fundamental role in human civilization and improved food security at the global and regional levels. It provides about 19% of the calories and 21% of protein needs of daily human requirements at the global level (Braun *et al*., 2010). Wheat is a staple food for 40% of the world's population, mainly in Europe, North America, and the western and northern parts of Asia. The demand for wheat is growing fast in new wheat-growing regions of the world, such as eastern and southern Africa (5.8%), West and Central Africa (4.7%), and South Asia and the Pacific (4.3%). Demand is also growing in the traditional wheat-growing regions of Central Asia (5.6%), Australia (2.2%), and North Africa (2.2%) (Shiferaw et al., 2013). Wheat is the most traded agricultural commodity at the global level, with a trade volume of 144 million tons and a total value of 36 billion US dollars (Shiferaw *et al.,* 2013). Many of the developing countries that depend on wheat as a staple crop are not self-sufficient in wheat production, and accordingly, wheat is their single most important imported commodity. Wheat also accounts for the largest share of emergency food aid (Dixon *et al.*, 2009).

## 2.3. Effect of Phosphorus and Potassium Application on Growth and Yield of Wheat

### 2.3.1. Effect of Phosphorus on Growth and Yield of Wheat

After nitrogen, phosphorus (P) is one of the nutrients that limits the growth and development of plants. It is the second most important nutrient in crop production and is crucial for plant growth (Salim, N. and Raza, A., 2020). The physiological functions of living things, especially plants, depend heavily on phosphorus (Mengel *et al.*, 2000). As a component of nucleic acids and phospholipids, phosphorus is an essential macronutrient that plays multiple roles in plant macromolecular structures. These roles include energy metabolism, participation in signal transduction pathways through phosphorylation and dephosphorylation, and regulation of important enzyme reactions (Wang *et al.*, 2019). It is one of the key macronutrients that regulate a variety of physiological processes in plants, influencing plant growth and overall production (Khan *et al.*, 2023). Phosphorus plays key roles in regulating plants' physiological responses to abiotic stresses. In plant cells, P is a component of nucleic acids, membrane lipids and phosphorylated intermediates of energy metabolism (Pratt *et al.*, 2009).

In addition, phosphorus regulates important enzyme processes and metabolic pathways like the Krebs cycle, glycolysis, and feedback inhibition (Brady and Weil, 2002). According to Hossain and Hamid (2007), it is important for energy conversions in plants and has a variety of functions in seed production. P encourages the growth of the root system and speeds up ripening, and enough P improves several physiological processes, including photosynthesis, blooming, seed formation, and maturation (Brady, 2002). Melese (2007) also reported P aids in the metabolism of energy transfer, signal transduction, macromolecular biosynthesis, photosynthesis, respiration chain reactions, and biomass production of micronutrients (Shenoy and Kalagudi, 2005).

Because of mobility in the plant, the deficiency symptoms first appear on the older leaves. However, with a more severe deficiency, plants become dark green to purplish in color. Phosphorus deficiency can reduce both respiration and photosynthesis, but if respiration is reduced more than photosynthesis, carbohydrates will accumulate, leading to dark green leaves. A deficiency can also reduce protein and nucleic acid synthesis, leading to the accumulation of soluble nitrogen (N) compounds in the tissue. Ultimately, cell growth is delayed and potentially stopped. As a result, symptoms of P deficiency include decreased plant height, delayed leaf emergence, and reductions in tillering, secondary root development, dry matter yield, and seed production (Fageria *et al*., 2003). Plants respond to P deficiency by adaptations that maximize the likelihood of producing some viable seed. Generally, P stress decreases the number of seeds produced more than seed size. In cereal crops, the reduction in seed number occurs through reduced numbers of fertile spikes and reduced numbers of kernels per spike. Reduction in leaf expansion and leaf surface area is the most striking effect in plants suffering from P deficiency (Brady and Weil, 2002). The deficiency of phosphorus might also limit nitrogen fixation through its effects on growth and survival of Rhizobia, nodule formation, nodule functioning, and host plant growth (Tang *et al.*, 2001). Phosphorus deficiency is a yield-reducing factor also in fertilized soil, particularly soils high in calcium carbonate, which reduces phosphorus solubility (Ibrikei *et al.*, 2005). Several authors indicated that application of P fertilizer at different levels has a significant impact on phenological, growth, yield parameters, and yield. It also stimulates root growth and photosynthesis (Singh and Sale, 2000). Wheat grain yield and yield contributing traits were significantly improved with fertilization of optimum P through soil application (Ahmad *et al.*, 2010; Rahim *et al*., 2010; and Rahmatullah *et al.*, 2007). Liakas *et al*. (2001) indicated that application of phosphorus and potassium favored the tillering of wheat. Ali et al. (2005) stated that the application of K and P on wheat crops increases the components of yield. Many studies revealed that application of phosphorus to wheat crops significantly increased the plant height, number of tillers per plant, straw, and grain yield over control (Noonari *et al.,* 2016). It strengthens the straw and increases flower formation and fruit production. Fixation limits its availability to plants in the soil environment (Brhan, 2012). Phosphorus promotes absorption of other nutrients and plant growth (Akamine *et al*., 2007). Alam *et al.* (2003), who observed that applications of phosphorus significantly affected the harvest, index of wheat crops. Plants acquire P in its inorganic form as orthophosphate H2PO4-/HPO42- from the soil solution (Marschner, 2012). The uptake mainly occurs in the form of H2PO4-ions in acid soils and in the form of HPO42-ions in basic or alkaline soils.

### 2.3.2. Effect of Potassium on Growth and Yield of Wheat

Potassium (K) is one of the essential nutrients required by plants in large amounts and plays a key role in plant growth and reproduction. Potassium is considered a primary mineral nutrient controlling crop plant response to various environmental stresses (Rengel and Damon, 2008). Potassium fertilization is frequently associated with improved crop quality as well as better handling and storage properties. Yawson *et al*. (2011) indicated that K promotes transportation of assimilates, controls stomata opening and enzyme activation, and promotes microbial activities in plants. Potassium increased the growth of macronutrient concentrations of leaves as well as enhanced the chlorophyll content of plants (Asgharipour and Heidari, 2011). Wheat takes more amount of K during the period of intensive biomass increment, i.e., from the beginning of stem elongation to the end of heading. At the end of vegetative development, K is the nutrient that decides about the pace of transport of assimilates into the ear. Limitation of

K supply at the stage of plant intensive growth results in disturbances of building the elements of yield structure. Adequate fertilization of K has a prominent role in decreasing certain plant diseases and improving quality. Potassium plays significant roles in transportation of water, nutrients, nitrogen utilization, stimulation of early growth, and insect and disease resistance, (Lakudzala, 2013; Jan, R., 2022). Potassium affects nitrate (NO3) absorption, where rapid NO3 depends on adequate K in the soil solution.

Potassium is a mobile nutrient in plants, and hence the deficiency symptoms appear on the older leaves, and it will move from lower to upper leaves, (Ali *et al.,* 2023). Some crops exhibit characteristic deficiency symptoms when adequate amounts of K are not available for growth and development. In wheat, potassium deficiency may result in shorter internodes, weaker straw, increased lodging, and slower growth. A yellowing of the leaf tip followed by marginal yellowing and dying of the tip may be noted. According to Madar *et al.,* (2020), approximately 90–98% of total soil K is found in the unavailable form depending on soil type. Feldspars and micas are minerals that contain most of the K, and some K moves to the slowly available pool whereas others move to the readily available pool. Laboratory tests from soil and plants indicated that the major deficiency symptoms observed in the plants are burning at leaf edges, which looks like disease, short internodes, relatively long leaves, and marginal and tip browning of leaves (FAO, 1995). Thus, deficiency of K in soils may result in decreased wheat yield Li, C., Zhao, X., *et al* 2020) and low enzyme glutamine syntheses and reduced yield in wheat K is deficient (Ali *et al*., 2005). Findings of research proved that application of K at different levels significantly affects the phenological, growth parameters, and yield components. The beneficial effect of K on increased wheat yield is due mainly to higher kernel weight, which resulted from increasing either the photosynthetic capacity or productive life flag leaves, which account for up to 80% of grain filling. A shortage of potassium is a cause for a reduction the physiological sink size in crop plants (Ali *et a., l* 2022). In the present day, intensive and high-yield-oriented agriculture, there is a negative K balance, and soils are being mined for this essential element (Tan *et al.*, 2005). Increasing K amount in wheat increased dry matter, TSW, tillers, and K contents in plant, plant height, protein contents, and grain yield (Kubar *et al.*, 2022). Fertilization of K increased crop quality, plant nutrition, and increased protein content (Gu, X., Liu, Y., et al 2021), productive tillers (Godebo, T., Laekemariam, F. *et al* 2021), plant height (El-Mageed, T.A.A., Semida, et al 2023) and grain yield (Tisdale *et al*., 2002). Baque *et al*. (2006) reported that the maximum effective tillers were recorded in wheat plants receiving a higher level of potassium. Potassium application significantly affects the harvest index of wheat (Brhane *et al*., 2017). Improved plant K status can increase grain set and yields in wheat under frost, likely by maintaining physiological functions such as cell osmoregulation, plant photosynthesis, and anti-oxidant systems (Ma *et al*., 2019).

### 2.3.3. Response of wheat to interaction effect of phosphorus and potassium

Nutrient interactions have a critical role in improving the growth and yield of the crop. Two or more elements working together to create an overall improved physiological state in the plant is called physiological synergism, while an excess of one nutrient reducing the uptake of another nutrient is called physiological antagonism. It is influenced by factors such as concentration of nutrient, temperature, light intensity, soil aeration, soil moisture, soil pH, architecture of root, the rate of plant transpiration and respiration, plant age and growth rate, plant species, and internal nutrient concentration of plants. Both P and K are essential for photosynthesis, enzyme/energy-driven reactions, seed formation and quality, stress tolerance, and crop maturity. These two mineral elements together shape nitrogen management in high-yield cultivation technologies, illustrating the agronomic and economic benefits of eliminating

P and K as limiting factors in crop production (Marschner, 1986). Several authors reported that the response of wheat to the combination of P and K. According to Hailu *et al*. (2017), the concurrent use of P and K significantly increased yield and the N, P, and K uptake of wheat as compared to the levels obtained with either P or K applied alone. Integration of P and K application improved the uptake of N, P, and K of wheat (Sharshar *et al*., 2000; Slaton et al., 2007). Akram *et al*. (2007) reported that P enhanced the crop growth, yield, and nutrient uptake more than K, whereas the best results were observed with the combined application of P and K. Liakas *et al.* (2001) indicated that the combined application of P and K favored the tillering of wheat. The application of K and P had significant effects on the dry matter yield, and the improvement in the grain yield due to the K and P additions could be attributed to the ameliorative effects of plant nutrition (K and P) on plant growth under salt stress conditions (Hussain *et al*., 2016).

### 2.3.4. Current Wheat Production Status in Ethiopia

Wheat production in Ethiopia is projected to reach a record level of 5.7 million metric tons (MT) for the 2022/23 season (Feyisa *et al* 2023). The Government of Ethiopia (GOE) has prioritized increasing production and productivity through initiatives such as small and large-scale irrigation development, financing agricultural inputs, encouraging cluster farming, and reducing post-harvest losses. Despite these efforts, challenges such as ethnic conflicts, security issues, and the impact of global events like Russia's war in Ukraine have affected farming activities and wheat supplies (USDA Foreign Agricultural Service, 2022).

### 2.3.5. Global and Local Adaptation Strategies for Wheat Production

Wheat is one of the most widely cultivated crops globally, and its adaptation strategies are crucial for ensuring food security. Researchers have identified adaptive genes, such as those related to vernalization and photoperiod response, which help wheat adjust to different climatic conditions by optimizing flowering and reproductive cycles (USDA, 2022). Expanding irrigation infrastructure and developing heat-tolerant crop varieties are key strategies, with countries like Canada and the U.S. investing in research to create wheat varieties that can withstand higher temperatures and drought conditions (Alam et al., 2003). Using climate models to predict future conditions helps in planning and implementing adaptation measures, including adjusting sowing dates and selecting appropriate crop varieties (Brhane et al., 2017).

In Ethiopia, climate change poses significant challenges due to altered temperature and precipitation patterns affecting wheat productivity. Land suitability analysis, considering soil properties, climate variables, and topographic characteristics, is used to identify suitable areas for wheat farming (USDA Foreign Agricultural Service, 2022). Developing and adopting new wheat cultivars, such as the Dandaa and Kakaba, which show better adaptation potential under different climate scenarios, is crucial. Implementing recommended agronomic practices, such as proper weeding and chemical spraying, enhances wheat productivity and resilience (Brhane et al., 2017). These adaptation strategies are essential for maintaining food security and supporting agricultural sustainability in Ethiopia.

### 2.3.6. Utilization of Wheat

Wheat is an incredibly versatile crop with a wide range of applications. It is primarily used in the production of food products, such as bread, pasta, noodles, cereals, and various baked goods. Wheat grains are milled into flour, which is a staple ingredient in many culinary recipes around the world (Alam et al., 2003). Additionally, wheat bran and other by-products from the milling process are commonly used in animal feed, providing essential nutrients for livestock (Brhane et al., 2017). Industrially, wheat can be fermented to produce ethanol, which is used as a biofuel, and wheat starch is utilized in the production of biodegradable plastics and certain types of textiles and paper products (USDA Foreign Agricultural Service, 2022). Moreover, wheat germ and wheat bran are rich in vitamins and minerals, often used in dietary supplements, while wheat grass is popular in health foods and beverages for its high nutrient content. Wheat extracts and oils are also ingredients in various cosmetic products due to their beneficial properties for skin and hair. In many cultures, wheat is part of traditional dishes and rituals, reflecting its cultural significance beyond just nutrition. This diverse range of applications makes wheat a crucial crop in global agriculture, contributing significantly to food security, economic stability, and industrial innovation.

### 2.3.7. Wheat Production, Demand, and Supply in Ethiopia

Wheat production in Ethiopia is projected to reach a record level of 5.7 million metric tons (MT) for the 2022/23 season, despite challenges such as ethnic conflicts and the impact of global events like Russia's war in Ukraine (USDA Foreign Agricultural Service, 2022). The Government of Ethiopia (GOE) has prioritized increasing production and productivity through initiatives such as small and large-scale irrigation development, financing agricultural inputs, encouraging cluster farming, and reducing post-harvest losses (USDA Foreign Agricultural Service, 2022). However, the demand for wheat has surpassed its production, and the country must import a projected amount of 1.4 million tons of wheat to meet its domestic consumption needs in the 2022/23 marketing year (USDA Foreign Agricultural Service, 2022). Economic growth and urbanization have further increased the demand for wheat flour, making it essential to address the supply-demand gap through continuous and sustainable production interventions (Brhane et al., 2017).

### 2.3.8. Proportion of Imported and Domestically Produced Wheat in Ethiopia

Ethiopia imports a significant proportion of its wheat to meet domestic demand. Despite efforts to increase local production, the country still relies on imports to fill the supply gap. It is estimated that Ethiopia imports around 30-40% of its wheat needs, with the remaining demand being met through domestic production (USDA Foreign Agricultural Service, 2022). This reliance on imports is due to various factors, including climate variability, limited arable land, and the need for improved agricultural practices and technologies (Brhane et al., 2017).

# 3. MATERIALS AND METHODS

## 3.1 Description of the Experimental Site

The experiment was carried out at Kechi Research Farm of Wolaita Sodo University, in Kechi Woreda of the Dawro Administrative Zone, South West Ethiopia, from July to November during the major cropping season of 2023. The study region spans 37°13'49.10″ to 37°14'18.05" E and 6°54′29.96" to 6°55′16.78″ N with Elevation of the research site is 2090 m.a.s.l. The site, receives 1355.4 to 2565.6 mm of annual rainfall, and experiences mean monthly temperatures ranging from 11.7 to 23.5 °C. Rainfall occurs in two distinct seasons: the short rainy season falls between March and May, while the long rainy season spans from June to September. The majority of the region is mountainous, with soil that is well-drained and has weathered somewhat. The farm soil in Kechi is classified as a luvisol (Abass, 2021).

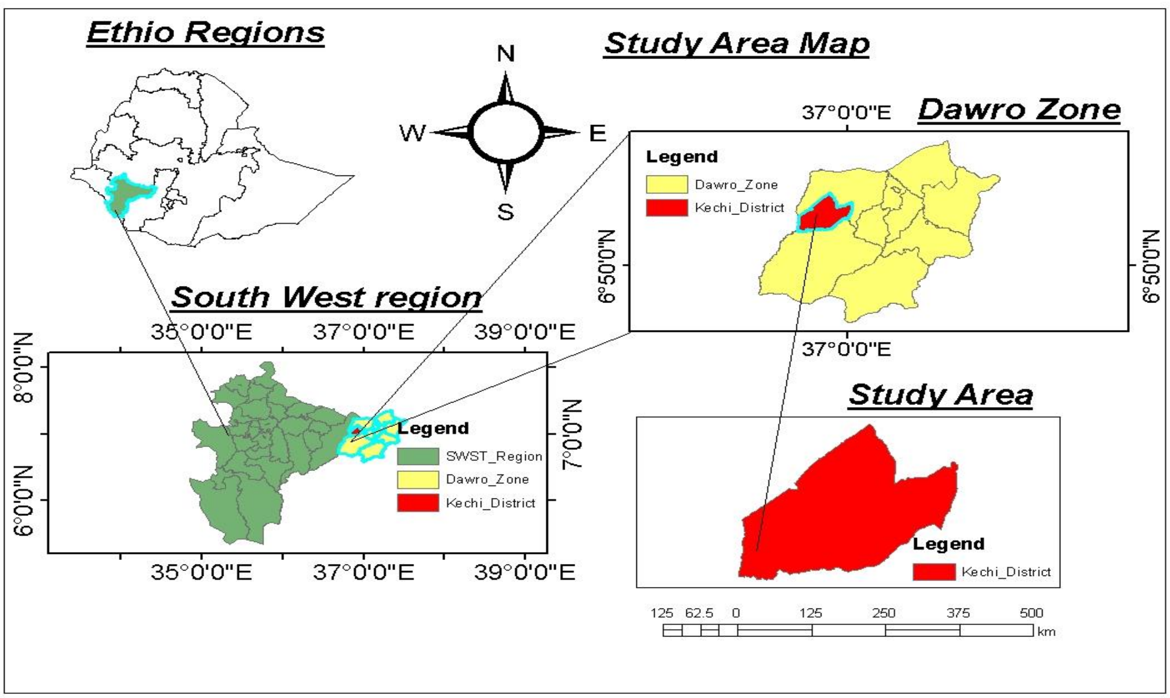


Figure 1: Location map of Kechi Woreda of Dawro Administrative Zone, South West Ethiopia

Source: Ethio-Shape files 2021

## 3.1. Meteorological Data of the Experimental Sites

### 3.1.2 Monthly average rainfall, maximum and minimum temperatures

Monthly average rainfall as well as the maximum and minimum temperatures during the cropping season of Kechi received 164.07 mm of rainfall during the main growth season, which ran from July to November (Figure 2). The study site experienced notably increased rainfall, with 232.5 mm recorded in August during the cropping season. This rainfall is critical for crop development, especially during the reproductive (flowering) stage. During this stage, enough water decreases floral abortion, promotes spike initiation and development, and increases seed and biological yield. Whereas, reduced the quantity of rainfall, is crucial for safe harvesting, especially November's minimal rainfall which recorded at 70.5 mm.

During the cropping season, the mean monthly maximum temperatures in Kechi range from 15°C to 19°C, with November being the highest and July being the lowest. During the primary agricultural season, October and November had the lowest and highest mean monthly minimum temperatures, respectively, ranging from 12.3 to14.5. °C. (Figure 2)

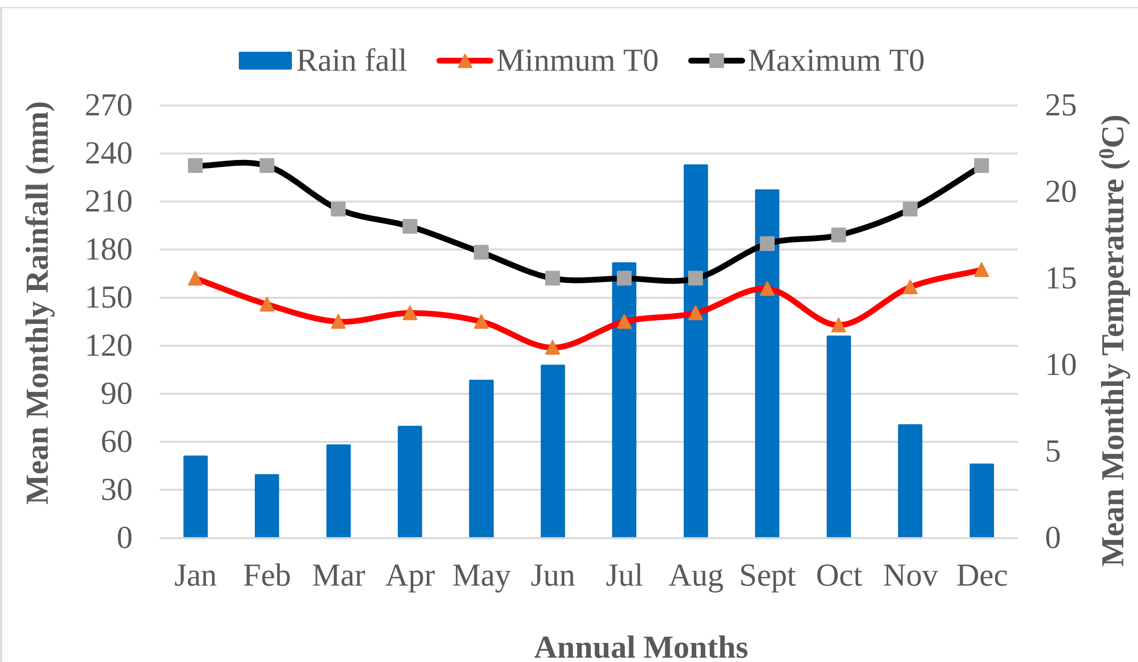


Figure 2. Total Annual Rainfall and Mean Minimum and Maximum Temperatures at Kechi Research Site, Dawro Administrative Zone, South West Ethiopia, during the 2023 Main Cropping Season.
Source; (PDAV: Power data access viewer)**; accessed November 2023**

### 3.2. Treatments and Experimental Design

Treatments used in this trial were four levels of P (0, 10, 20, and 30 kg/ha) and three levels of K (0, 30 and 60 kg/ha) in the form of triple supper phosphate (46 kg P2O5) and KCl (murates of potash, 60% K2O), respectively. The treatments were laid out in a randomized complete block design (RCBD) using a factorial arrangement with three replications with a plot area of 2 m X 1.8 (3.6 m2) and a net plot area of 2 m x 1.4 (2.8 $m^2$). Wheat variety, Hidase, which was released by Kulumsa Agricultural Research Center in 2012, was used as a test crop. This variety is grown in wide environmental conditions, having an altitude of 2200 to 2600 m.a.s.l. and rainfall of greater than 500 mm. The variety is able to produce grain yields of 4.4–7 t/ha on station and 3.5–6 t/ha on farm station (MOA, 2013). Planting was carried out in the first week of July following the planting practices of the farmers in the area. The full dose of fertilizers was applied at planting by drilling along the rows at 20 cm intervals with a seed rate of 125 kg/ha.

Table 1: Treatment Combinations of the Experiment

| Treatment Combination | Phosphorus (P) Levels(kg/ha) | Potassium (K) Levels (kg/ha) |
|---|---|---|
| 1. 0 P kg/ha x 0 K kg/ha | 0 | 0 |
| 2. 0 P kg/ha x 30 K kg/ha | 0 | 30 |
| 3. 0 P kg/ha x 60 K kg/ha | 0 | 60 |
| 4. 10 P kg/ha x 0 K kg/ha | 10 | 0 |
| 5. 10 P kg/ha x 30 K kg/ha | 10 | 30 |
| 6. 10 P kg/ha x 60 K kg/ha | 10 | 60 |
| 7. 20 P kg/ha x 0 K kg/ha | 20 | 0 |
| 8. 20 P kg/ha x 30 K kg/ha | 20 | 30 |
| 9. 20 P kg/ha x 60 K kg/ha | 20 | 60 |
| 10. 30 P kg/ha x 0 K kg/ha | 30 | 0 |
| 11. 30 P kg/ha x 30 K kg/ha | 30 | 30 |
| 12. 30 P kg/ha x 60 K kg/ha | 30 | 60 |

### 3.3. Agronomic Practice

The experimental field was ploughed, pulverized, and leveled in order to get a smooth seedbed. All plots received an equal application of 69 kg/ha of the optimal amount of nitrogen (46 kg N) in the form of urea, with the first half being treated during planting and the remaining N being administered as top dressing during tillering. Every aspect of crop management, including weeding, cultivation, and so on, is done as intended. Observations were made of diseases and insect damage throughout the crop-growing season.

### 3.4. Soil and Plant Sampling and Data Collection

#### 3.4.1. Soil data

Before planting, 10 random (0-20 cm) soil samples were obtained from the entire experiment field in a zigzag pattern using a soil auger to form one composite sample. After being allowed to air dry and powdered until it could fit through a 2 mm filter, the sample was examined for a few key physico-chemical characteristics. Particle size analysis was carried out using a hydrometer (Bouyoucos, 1962), soil pH (Roades, 1982), organic matter (Walkley and Black, 1934), and the ammonium acetate method (Busenberg and Clemency, 1973) to determine the cation exchange capacity (CEC). Total nitrogen was assessed by the Kjeldhal method (Bremner *et al.*, 1982). Using the Mehlich-III technique, extractable B, Zn, and Fe, exchangeable K+, available phosphorus, sulfur, calcium (Ca), and magnesium (Mg) were obtained (Mehlich, 1984).

## 3.5. Data Collection

### 3.5.1. Phenological parameters

**Days to Heading:** This stage is determined by counting the number of days from the date of emergency to when 50% of the plants has reached the heading stage, where 50% of the spikes of ten randomly selected plants are producing seeds.

**Days to Physiological Maturity:** This is determined by counting the number of days from emergency to the date when 90% of the straw has a yellow color, indicating the plants have reached physiological maturity.

### 3.5.2. Growth parameters

**Plant height**: It was measured at physiological maturity from ten randomly selected plants per plot from ground level to tip excluding the own.

### 3.5.3. Yield and yield components

**Number of tillers**: The number of tillers per unit area was calculated using ten randomly pre-tagged plants per plot at the heading.

**Number of Productive Tillers:** This is determined by counting all spikes producing seeds from ten randomly selected plants. Each spike producing seeds from these selected plants is considered for the count to provide a representative measure of productive tillers.

**Numbers of Grains per Spike:** The mean number of grains per spike was calculated by averaging 10 randomly selected spikes from the central unit area, which were then threshed and the grains counted with an electronic seed counter.

**Thousand Seed Weight (TSW):** This was determined by randomly selecting 1000 seeds from the standing crop, specifically from plants sampled for yield data. These seeds were then weighed using a sensitive balance. The seed weight was corrected to 12% moisture content using a grain moisture meter (Model GMM) to ensure accuracy and consistency in the measurements.

**Biomass Yields (ABM) (kg ha⁻¹):** Biomass yields were recorded from the net plot area, which is the central unit area encircled within the plot. This was done by weighing the total above-ground biomass at the time of harvesting.

**Straw yield**: It was calculated by subtracting the total grain yield from the corresponding total above-ground biomass yield.

**Grain Yields (kg ha⁻¹):** Grain yields were measured at harvesting from plants within the central unit area of the plot. The harvested grains were then adjusted to 12% moisture content to ensure consistency and accuracy in the yield measurements. The adjustment to 12% moisture content was done using the following formula:

$$\text{Moisture content} = \frac{(\text{Harvest yield})(100 - \text{Harvest moisture }\%)}{(100 - Standard\ moisture\%}$$

**Where:**

Harvest Yield is the yield measured at harvesting.

Harvest Moisture % is the moisture content of the grains at the time of harvest.

Standard Moisture % is the desired moisture content, which is 12%.

**Harvest index (%):** From the above ground biomass yield and grain yield data, the crop harvest index plot$^{-1}$ was calculated using the formula.

$$Harvest\ index = \frac{Grain\ yield}{Above\ ground\ biomas} X100$$

**3.6. Data Analysis**

The data were analyzed using the general linear model (GLM) procedure of Statistical Analysis System (SAS) version 9.20 (SAS, 2008). Mean separation was done using least significant difference (LSD) at 5% of probability level whenever significance differences among treatment are detected.

### 3.7. Economic Analysis

The economic analysis aimed to assess the profitability of KCl and TSP fertilizer and determine their agronomic effectiveness using the partial budget method outlined by CIMMYT (1988). Economic analysis were calculated using the formula established by CIMMYT (1988)

**Unadjusted Grain Yield (UGY) (t ha$^{-1}$):** It was the average yield of each treatment.

**Adjusted grain yield (AGY) (t ha$^{-1}$):** It was the average yield adjusted downward by 10% to reflect the difference between the experimental yield and the yield that a farmer could expect from the same treatment without the researchers' involvement (CIMMYT, 1988).

**Gross field benefit (GFB) (ETB ha$^{-1}$):** It was computed by multiplying the field/farm gate price (65 ETB kg$^{-1}$) that farmers receive for the crop when they sell it as an adjusted yield. GFB = AGY × field/farm gate price for the crop.

**Total variable cost (TVC) (ETB ha$^{-1}$):** It included the current price of TSP fertilizer (275 ETB kg$^{-1}$), and price of KCl fertilizer (250 ETB kg$^{-1}$) Wheat seed (90 ETB kg$^{-1}$), and as well as the labor cost for all activities, which was considered the sum of all costs variable.

**Net benefit (NB) (ETB ha$^{-1}$):** It was calculated by subtracting the total variable costs (TVC) from gross field benefits (GFB) for each treatment as NB = GFB-TVC.

Dominance analysis involved organizing treatments in order of increase TVC and the corresponding NB. Treatments with higher TVC but lower NB compared to the preceding treatment with lower TVC but higher NB were identified as dominant (marked as "D").

**Marginal rate of return (MRR) (%):** It was calculated as the change in net benefits (ΔNB = NB Treatment-NB Control) by the change in total variance cost (ΔTVC=TC Treatment-TC Control) and then multiplied by 100. MRR (%) = × 100

# 4. RESULTS AND DISCUSSION

## 4.1. Soil Physico-chemical properties at the Study Site

Selected soil physicochemical properties of the study site evaluated before conducting the experiment are presented in Table 2. The soil of the study area is clay- textured, with a particle size distribution of 42% clay, 38% silt, and 20% sand. The soil pH was 5.8, which is considered mildy acidic (EthioSIS, 2014). It implies the existence of significant quantities of cations such as $H^{+,}$ $Fe3^{+}$, and $Al3^{+.}$ Wheat has been shown to grow well in pH value ranges of 6–7, although the optimum growth occurs at pH 5.5-7, and any pH below these ranges inhibits its growth. Toxic elements ($Al^{++}$ and $Fe^{++}$) concentrations in such acidic soils reduces wheat's uptake of K, Ca, Mg, and B. Farmers can improve the soil quality in acidic soils by liming to adjust pH to the levels needed by the crop to be grown. The OC content in the soils was 4.48 percent, which is rated as ranked low, and the soil total nitrogen percentage (TN%) was 0.44%, categorized under medium soil TN content and requires nitrogen application (Landon, 2014). The low percent of OC and TN in soil could be attributed to the complete removal of residue (Fanuel and Kibebew, 2020) and excessive tillage (Saljinkov *et al*., 2009).

The available P (2.74 mg $kg^{-1}$) is rated as very low (EthioSIS, 2014). The cation exchange site was occupied in the order of Ca>Mg>K>Na. The soil had Ca, Mg, K, and Na values (cmol (+) $kg^{-1}$) of 4.33, 0.75, 0.24, and 0.07 cmol (+) $kg^{-1}$, respectively which were rated as low (Landon, 2014). The concentration of micronutrients in soil was found to be in the order Fe>Mn>Zn>Cu>B. According to EthioSIS, 2014to Fe was very high, B was very low, Mn was high, and Zn and Cu were at their optimum. Furthermore, high Fe concentrations are harmful to most of the crop species (Jones, 2003).

Table 2: Soil physicochemical characteristics of Kechi before experiment application during 2023 main cropping season

*Where: CEC=Cation Exchanging Capacity OC= Organic carbon, TN =Total nitrogen*

| Parameter | Unit | Result | Rate | References |
|---|---|---|---|---|
| Soil particle size distribution | | | | |
| sand | % | 20 | | |
| Silt | % | 38 | | |
| Clay | % | 42 | | |
| Soil texture | | Clay | | Soil textural triangle (Marcel Dekker Inc., 2004) |
| pH | | 5.8 | Moderately acidic | EthioSIS, 2014 |
| % OC | % | 4.48 | Low | Landon, 2014 |
| %TN | % | 0.44 | Medium | Landon, 2014 |
| Available P | $mgKg^{-1}$ | 2.74 | Very low | EthioSIS, 2014 |
| Available potassium | cmol(+)Kg | 0.24 | Low | EthioSIS, 2014 |
| CEC | $cmol(+)Kg^{-1}$ | 37.72 | Very high | Hazelton and Murphy (2007) |

## 4.2. Crop Phenology

### 4.2.1. Days to heading

Statistical analysis indicated that days to heading were significantly influenced by the main effects of P and K fertilizer rates and their interaction (Appendix Table 1). The days to heading ranged from 52 to 62, observed in plots treated with 30 kg/ha P and 60 kg/ha K and unfertilized plots, respectively (Figure 3). The results indicated that increasing rates of both P and K fertilizers tended to reduce the days to wheat heading. This is likely because the combined application of P and K enhances plant growth by improving nutrient uptake. This timely nutrient availability promotes early vegetative growth and the subsequent initiation of reproductive growth. This finding is in line with results of Brady (2002), Marschner (2012), and Lakudzala (2013) who reported that an adequate supply of P and K stimulated early growth and flowering in wheat.

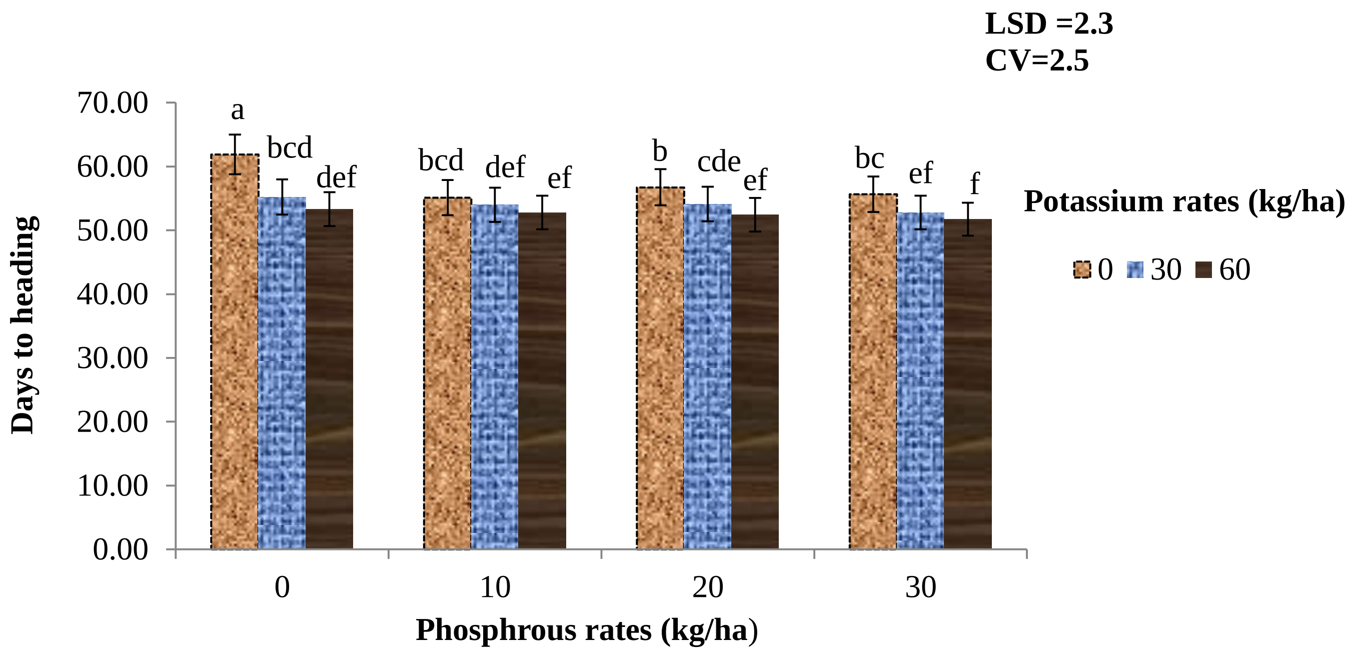


Figure 3. Days to heading as affected by the interaction of P and K fertilizer rates at Kechi during 2023 main cropping season

#### 4.2.2. Days to physiological maturity

Days to physiological maturity were significantly (P< 0.05) influenced by the main effects of P and K fertilizer rates and their interaction (Appendix Table 1). In general, days to physiological maturity as affected by the interaction of P and K fertilizer rates ranged from 101.To 117 (Figure 4). Days to physiological maturity exhibited inconsistency with increasing P rates across all levels of K as well as with increasing K rates across levels of P rates. The longest days to physiological maturity (117) were recorded from non-fertilized plots. While the shortest (101) from 20 kg/ha P combined with 30 kg/ha K fertilizer rate. The difference of 16 days was recorded between the longest and shortest days to physiological maturity (Figure 4). That is the evidence the physiological maturity in wheat was shorted as P and K fertilizer rates increased. This might be due to the applied nutrients activating the transportation of water and nutrients in the plant that improved the photosynthetic reaction of the plant, which resulted in simulation of early growth and maturation. This result is concomitant with the reports of Ma *et al.* (2006) and Slaton *et al.* (2007), who indicated the potential benefits of providing sufficient P and K for wheat, as well as other plants, for promoting early plant maturity. Therefore, the combined application of P and K fertilizers fastened the early growth and maturation.

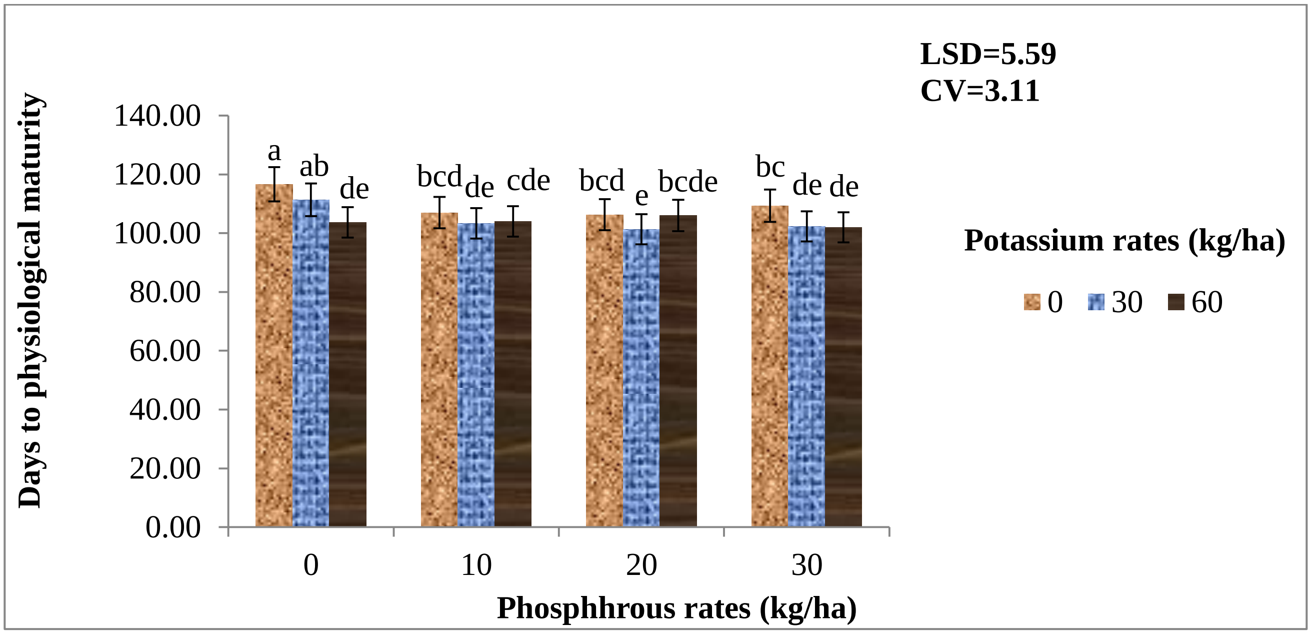


Figure 4. Days to physiological maturity of wheat as affected by interaction of P and K at Kechi during 2023 main cropping season

### 4.3. Growth Parameters

#### 4.3.1. Plant height

Analysis of variance showed main factors of P and K fertilizer rates and their interaction resulted in significant ($P \leq 0.05$) differences in plant height (Appendix Table 1). All plots fertilized with P and K had taller plants as compared to unfertilized plots. The tallest plants (95.3 cm) were observed at P rate 20 kg/ha combined with K rate 30 kg/ha, P rate 30 kg/ha combined with K rate 60 kg/ha, P rate 20 kg/ha combined with K rate 60 kg/ha, and fertilizer combination of 30 kg/ha P with 30 kg/ha K with a mean plant height of 94.5 cm (Figure 5). While the shortest plant height was recorded from unfertilized plots 0 kg/ha P with 0 kg/ha K (54.7 cm) (Figure 5). This result clearly indicated plant height is closely associated with increasing levels of P and K fertilization. This could suggest that they stimulate the physiological processes in plants that increase in the number and size of growing cells, resulting in increased plant height in wheat. However, without fertilizers, plants lack essential nutrients necessary for their growth processes. Deficiencies in P and K can lead to stunted growth due to inadequate energy transfer and poor root development. Unfertilized plots might not provide sufficient organic matter or micronutrients needed for healthy plant development. This result is in agreement with the findings of Noonari *et al.* (2016) and Rahmatullah *et al.* (2007) that P and K fertilization significantly influenced plant height of wheat. Similarly, Chapman and Mason (1969) stated that plant heights of wheat were increased by combining the P and K nutrients.

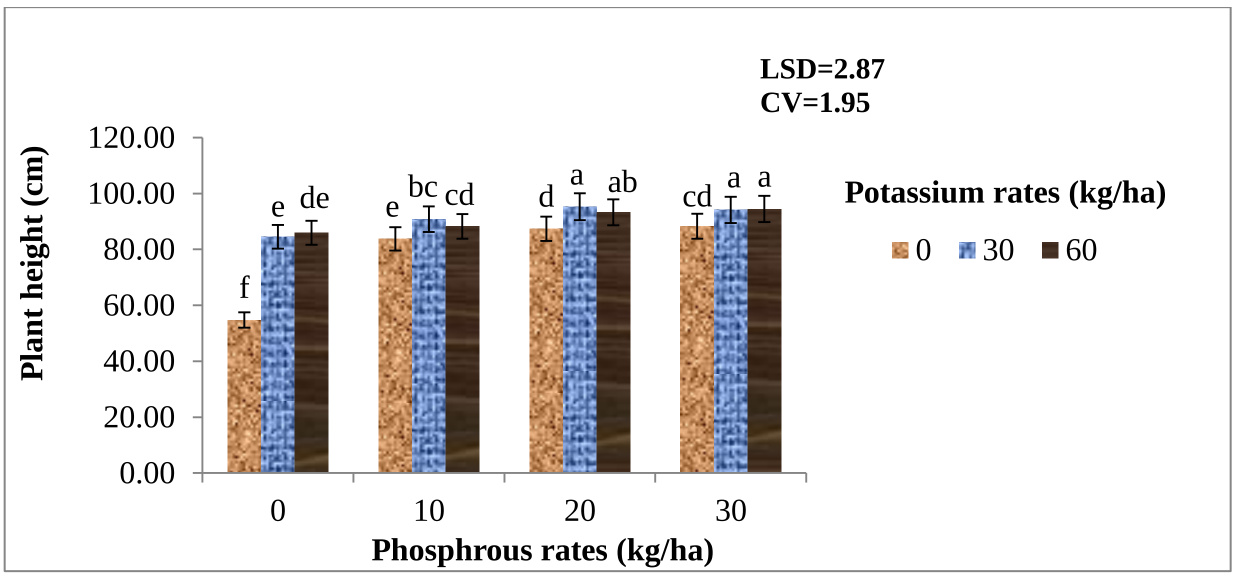


Figure 5. Plant height (cm) of wheat as affected by interaction effect of P and K fertilizer rates at Kechi during 2023 main cropping season

## 4.4. Yield and Yield Components

### 4.4.1. Total tiller number

The total tiller number of plants per unit area was significantly influenced by the main effects of P and K fertilizer rates and their interaction (Appendix Table 2). The highest total tiller number per plant (510) was recorded from the combined P and K rates of 20 kg/ha P with 30 kg/ha K, followed by the combination of 30 kg/ha P with 60 kg/ha K, with a mean total tiller number per unit area of 497. The least total tiller number per plant (345) was recorded from plots with 0 kg/ha P and 10 kg/ha P combined with 0 kg/ha K, which share the same letter, indicating no significant difference between them. The least tiller number (346) was also noted from the combination of 20 kg/ha P with 0 kg/ha K, showing a slight increase but still low tiller numbers.

This increase in total tiller number per plant in fertilized plots is attributed to the improved root systems that allow for better absorption of water and nutrients from the soil. Adequate nutrients enable plants to produce more chlorophyll and carry out photosynthesis more efficiently, promoting the production of more tillers. In contrast, unfertilized plots, where no additional nutrients are provided, lack essential nutrients like P and K, limiting the plant's ability to grow optimally. Without sufficient nutrients, plants cannot produce enough energy through photosynthesis, resulting in fewer tillers as the plant prioritizes survival over reproduction. This finding aligns with Liakas et al. (2001), who indicated that the application of P and K favored the tillering of wheat. Furthermore, adding P and K to wheat increased the number of tillers (Alam et al., 2002; Bachmanyar and Ranjbar, 2008).

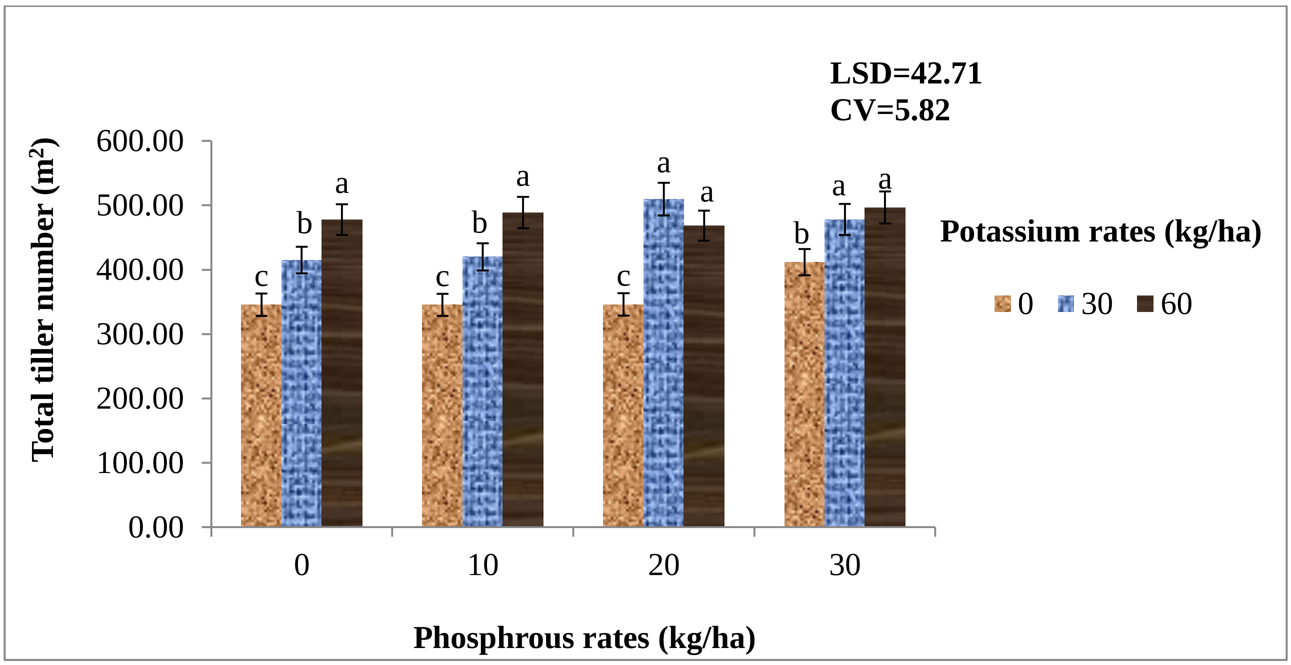


Figure 6. Total tiller number (m2) of wheat as affected by interaction of P and K fertilizer at Kechi during 2023 main cropping season

#### 4.4.2. Productive tiller number

Productive tiller number per m² was significantly (P<0.05) affected by P and K rates, but not by their interactions (Appendix Table 2). The number of productive tillers did not consistently increase with P fertilizer rates. The highest number of productive tillers (365.53) was observed at a P rate of 30 kg/ha, while the lowest number (331.91) was seen at a P rate of 10 kg/ha, combined with 0 kg/ha K. This shows that the response to P rates varied depending on the specific combination of P and K rates used.

Enhanced nutrient uptake due to adequate phosphorus can support more vigorous growth and better tiller survival rates. However, insufficient P can lead to stunted growth and fewer tillers, as seen in the lower productive tiller numbers at certain P rates. The results indicate the complexity of nutrient interactions and their effects on plant growth, consistent with the findings of Bashir et al. (2015), who noted increased productive tillers with adequate P nutrients.

Similarly, K fertilizer rates resulted in significant differences in the number of productive tillers (Appendix Table 2). The number of productive tillers generally increased with higher K rates. The highest number of productive tillers (355.39) was recorded at a K rate of 60 kg/ha, closely followed by 30 kg/ha K with a mean productive tiller number of 354.72. The least number of productive tillers (331.42) was observed at 0 kg/ha K. Potassium influences hormonal balance within plants, particularly auxins and Cytokinins, which are critical for cell division and differentiation processes leading to tiller formation. Higher potassium levels promote better root growth, enabling plants to access more water and nutrients from the soil, thus supporting more tiller formation. Lack of potassium results in suboptimal physiological processes within wheat plants, leading to fewer productive tillers. This finding aligns with Tahir et al. (2003), who reported that increased K fertilization promotes the production of productive tillers.

Table 3. Productive tillers ($m^2$) as affected by main effects of P and K fertilizer rates at Kechi during 2023 main cropping season

| P rate (Kg/ha) | Productive tillers |
|---|---|
| 0 | 341.03[b] |
| 10 | 331.91 [b] |
| 20 | 348.01[ab] |
| 30 | 365.53[a] |
| LSD (0.05) | 20.747 |
| **K rate (kg/ha)** | **Productive tillers** |
| 0 | 331.42 [b] |
| 30 | 354.72 [a] |
| 60 | 355.39[a] |
| LSD (0.05) | 17.967 |
| CV (%) | 6.11 |

*LSD (0.05) =Least Significant Difference at 5% level; CV=Coefficient of Variation; Means in column followed by the same letters are not significantly different at 5% level of significance*

**4.4.3. Number of grains per spike**

Grains per spike revealed that the main and interaction effects of P and K fertilizer application rates had a significant ($P \leq 0.05$) effect on the number of grains spike$^{-1}$ (Appendix Table 2). The number of grains per spike increased with increasing K rates at all levels of P fertilizer rates. On the other hand, a higher number of grains per spike was observed at a K rate of 30 kg/ha for all levels of P rates (Figure 7). In general, all fertilized plots outperformed the unfertilized plots. The greatest number of grains per spike (58.333) was recorded at a P and K fertilizer rate combination of 20 kg/ha P with 30 kg/ha K and a P rate of 10 kg/ha combined with 30 kg/ha K, with a mean number of grains per spike of 51.833. The least number of grains per spike (23.167) was obtained from non-fertilizer application plots (Figure 7). The result showed that the combination of 20 kg/ha P with 30 kg/ha increased the number of grains per spike by 151.7 % higher than the control. According to the result, application of P and K fertilizer showed increased grains per spike than the treatments without fertilizer applied, and that might be the response of the applied fertilizer contribution to hasten flowering and seed formation by producing more grains. The result showed that application of P and K fertilizers promoted grain formation and development in wheat through enhancing transportation of assimilates enzyme activation, protein synthesis, and flowering. This result agreed with the finding of Laghari *et al*. (2010), who reported that the application of K and P to wheat significantly enhanced yield components**.** Similarly, Damene, (2003) and Baque *et al*. (2006) reported that application of P and K, respectively stimulated the growth and development of wheat and leading to a higher number of grains per spike.

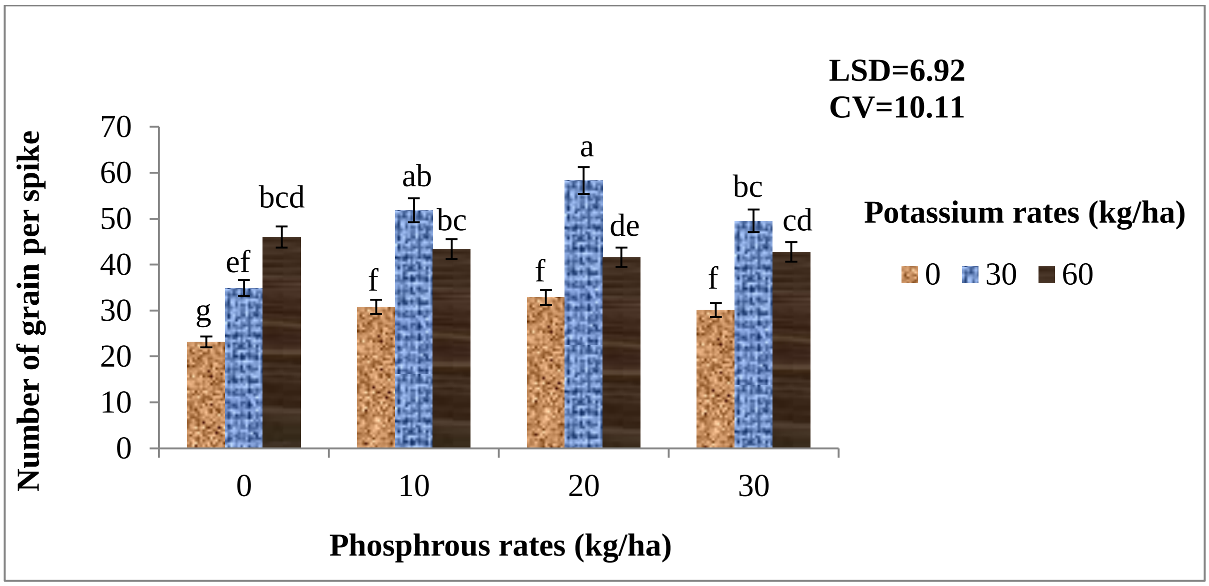


Figure 7: Number of grain per spike of wheat as affected by interaction of P and K fertilizer rates at Kechi during 2023 main cropping season

#### 4.4.4. Thousand Seed weight

Thousand seed weights significantly (P≤0.05) differed due to the main effect of P and K fertilizer rates and their interaction (Appendix Table 2). The highest thousand seed weight (54.9 g) was achieved from P rate 20 kg/ha combined with 30 kg/ha K fertilizer, followed by the combination of 30 kg/ha P with 60 kg/ha K with a thousand seed weight of 52.5 g. The lowest thousand seed weight (30.57 g) was seen on the unfertilized plot (Figure 8). This result might signify the role of P and K in improving photosynthetic activity and enhancing assimilate transport to grain ripening, which resulted in heavier grains, increased grain number, and 1000 grain weight. While the lowest seed weight was recorded from an unfertilized plot due to a lack of sufficient phosphorus, plants might struggle with energy transfer processes necessary for growth and reproduction. Additionally, a lack of potassium can result in poor water regulation within the plant cells, leading to stress conditions that inhibit growth. Overall nutrient deficiency can lead to stunted growth and reduced seed size due to inadequate resources being available for developing seeds. The result agreed with Ali *et al*. (2005), who stated the application of P and K had a significant effect on the thousand seed weight.

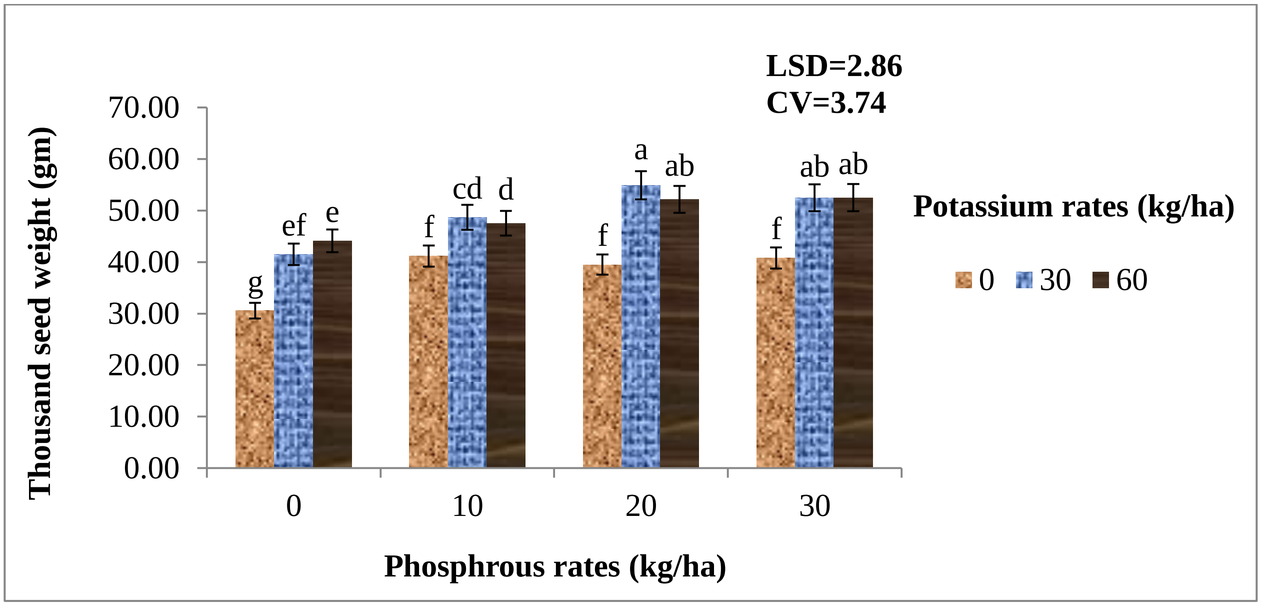


Figure 8.Thousand seed weight (gm) of wheat as affected by interaction of P and K fertilizer rates at Kechi during the 2023 main cropping season.

**4.4.5. Above ground biomass yield**

The result revealed that the main effects of P and K fertilizer rates as well as their interaction showed a significant difference in above-ground biomass yield of wheat (Appendix Table 3). Above-ground biomass yield was affected by the interaction of P and K fertilizer rates, which ranged from 2893.3 to 9646.7 kg/ha (Figure 9). All fertilized plots out yielded the unfertilized ones. Above-ground biomass yield showed the tendency to increase with increasing P rates at all levels of K fertilizer rates. Similarly, it increased with K rates across all levels of P fertilizer rates. Above-ground biomass is a function of numerous interacting environmental and genetic factors, and its production is directly related to potential growth and development factors such as solar radiation, water supply, availability of mineral nutrients, and crop management practices. The greatest above-ground biomass yield (9646.7 kg/ha) was recorded at a P rate of 30 kg/ha combined with a K rate of 60 kg/ha, followed by 20 kg/ha P combined with 60 kg/ha K with a mean biomass yield of 9280 kg/ha. The lowest biomass yield (2893.3 kg/ha) was achieved from unfertilized plots (Figure 9). Different authors reported application of P alone or its combination with K associated with positive contribution on biomass production in wheat. This finding is in conformity with those reported by Hailu *et al*. (2017) that application of P and K significantly improved the aboveground biomass yield of wheat. Jiang *et al.* (2006) indicated that P applications resulted in increased production of leaf area, LAI, and tillers, leading to increased biomass yield production. The findings of Hussein *et al*. (2004) and Wassie *et al*. (2013) showed that increasing rates of P and K fertilizer corresponded to a proportional increase in biomass production in wheat.

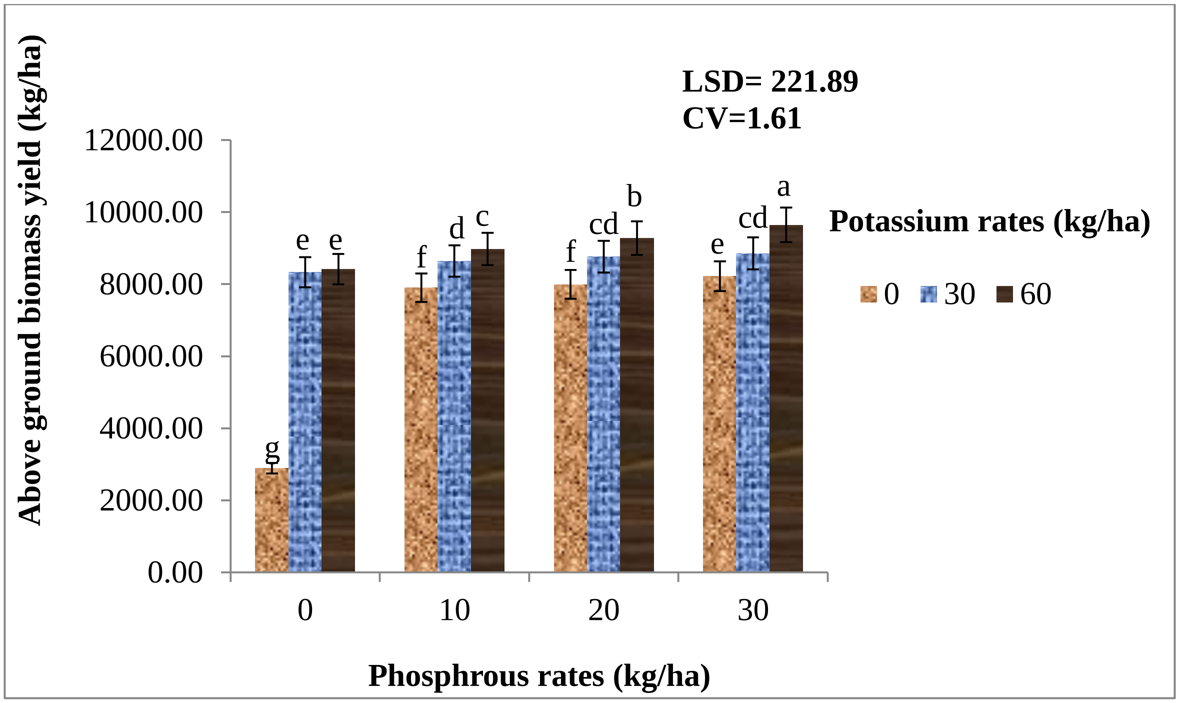


Figure 9 Above ground dry biomass (kg/ha) of wheat as affected by interaction effect of P and K fertilizer rate at Kechi during 2023 main cropping season

#### 4.4.6 Grain yield

Grain yield of wheat was significantly ($P \leq 0.05$) influenced by the main effects of P and K fertilizer rates as well as their interaction (Appendix Table 3). Grain yield varied from 649.7 to 4724.3 kg/ha (Figure 10). In general, grain yield tended to increase with increasing P rates at certain levels of K fertilizer rates, but this trend was not consistent across all levels. For instance, at a K rate of 0 kg/ha, the grain yield decreased from 649.7 kg/ha at 0 kg/ha P to 3210.0 kg/ha at 10 kg/ha P, but increased again at higher P rates. Conversely, grain yield tended to increase with K rates up to 30 kg/ha and then declined with further increases above 30 kg/ha K for all P fertilizer rates.

The greatest grain yield (4724.3 kg/ha) was recorded at a combined P and K rate of 20 kg/ha P and 30 kg/ha K, followed by 30 kg/ha P combined with 30 kg/ha K with a mean grain yield of 4406.3 kg/ha. The lowest grain yield (649.7 kg/ha) was obtained from the control plot with no fertilizer application. This indicates that all fertilized plots generally produced higher grain yields compared to unfertilized plots.

Crop yield is influenced by several factors and processes, such as the amount of light intercepted by the canopy, the metabolic efficiency of plants, and the translocation efficiency of photosynthesis from leaves to economic parts. These processes are enhanced by adequate P and K fertilization. Differences in P and K fertilizer rates significantly impacted wheat grain yield by influencing yield components. For example, the interaction rate of 20 kg/ha P and 30 kg/ha K resulted in 627.2% higher yields compared to the control, demonstrating the importance of optimal P and K fertilizer combinations. Excessive K beyond 30 kg/ha resulted in reduced yields, highlighting the need for balanced fertilization.

The synergistic effect of P and K fertilization on grain yield is due to their contributions to physiological processes such as photosynthesis, flowering, seed formation, maturation, and disease resistance. This aligns with findings from Laghari et al. (2010) and Hailu et al. (2017), who reported significant yield increases with the concurrent use of P and K compared to single applications. Zhang et al. (1999) also found that P fertilization improved tiller numbers, photosynthetic activity, and translocation to grain filling, leading to increased grain yield. Furthermore, studies by Hussein et al. (2004), Haile et al. (2012), and Maurya et al. (2014) showed that P and K fertilizers alone or in combination significantly increased wheat grain yield.

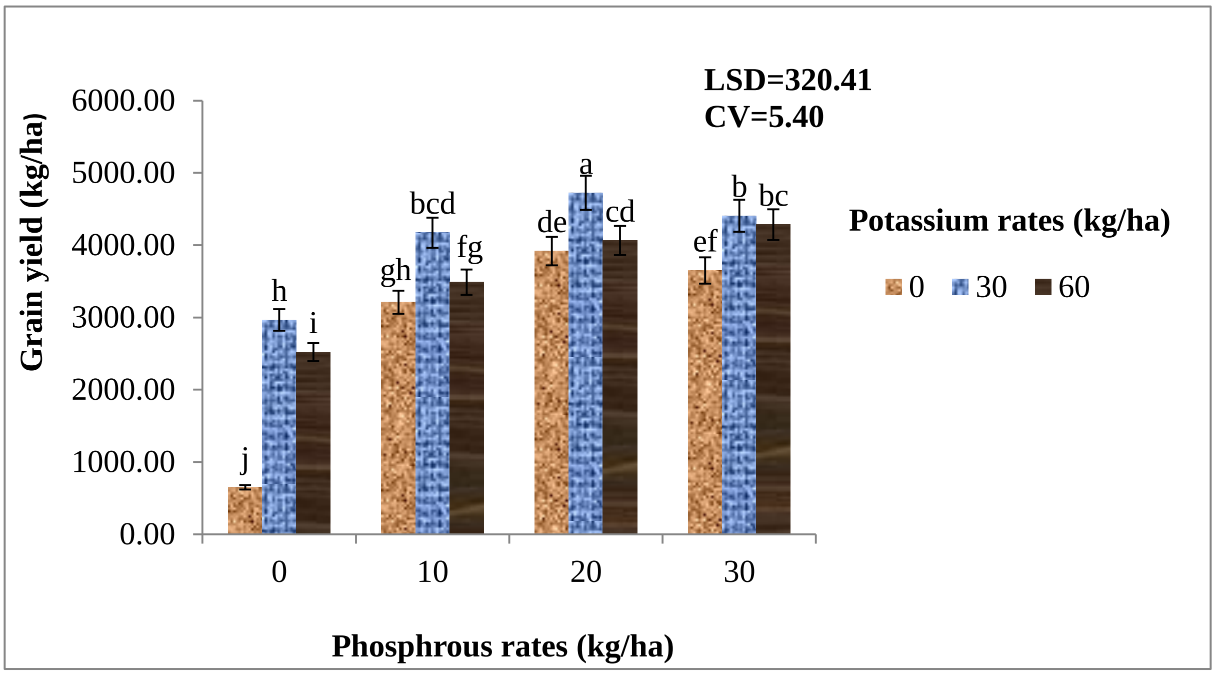


Figure 10 : Grain yield (kg/ha) of wheat as affected by the interaction effect of P and K fertilizer rate at Kechi during 2023 main cropping season

#### 4.4.7. Straw yield

Analysis of variance revealed that the main effects of P and K fertilizer rates and their interaction had significant ($P \leq 0.05$) differences on straw yield (Appendix Table 3). All fertilized plots yielded higher straw yield than unfertilized plots. However, the differences among fertilized plots for straw yield were not statistically significant (Figure 11). The increase in straw weight may have been due to the role of applied nutrients to increase tillering, leaf area, and also plant height. This application of phosphorus significantly increased straw of wheat over control (Alam *et al*., 2002). Another finding of Astatke *et al*. (2004) and Saha *et al*. (2010) reported that potassium fertilizer increased straw yield of wheat at various rates.

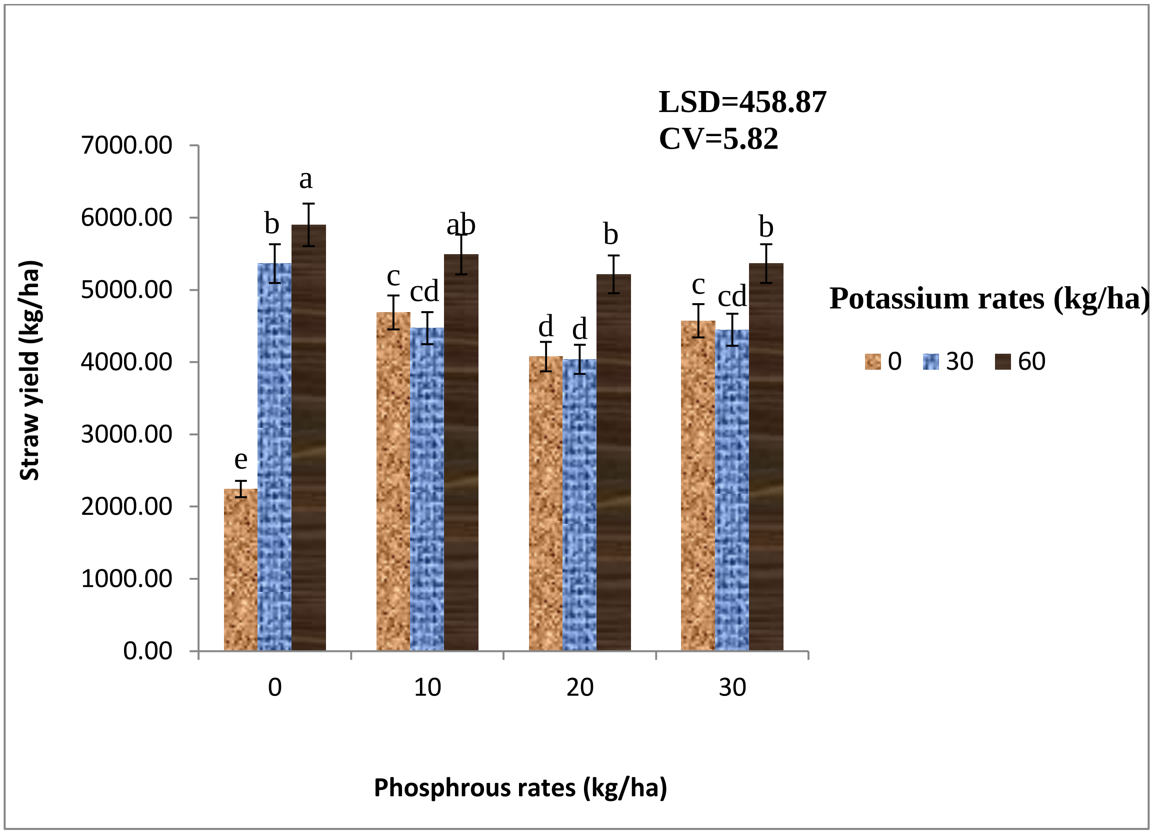


Figure 11 Straw yield (kg/ha) of wheat as affected by the interaction of P and K fertilizer rates at Kechi during 2023 main cropping season

**4.4.8. Harvest index**

Phosphorus (P) Rates: The HI ranged from 0.224 c to 0.490, representing an increase of approximately 68% when comparing the unfertilized plots to the plots treated with 20 kg/ha of P (highest HI). The highest HI (0.490) was recorded at a P rate of 20 kg/ha, followed by a mean HI of 0.444 at 30 kg/ha. The lowest HI (0.224) was observed in unfertilized P plots. This indicates that increasing P rates tend to enhance the HI, suggesting more efficient nutrient and dry matter partitioning into grain production. This finding is consistent with Alam et al. (2003), who also noted significant effects of phosphorus application on the harvest index of wheat.

Potassium (K) Rates: The HI ranged from 0.224 to 0.356, showing an increase of approximately 22% when comparing the unfertilized plots to the plots treated with 30 kg/ha of K (highest HI). The highest HI (0.356) was recorded at 30 kg/ha of K, while the lowest HI (0.224) was observed in unfertilized plots. The application of K fertilizer significantly increased the HI of the wheat crop, corroborating the findings of Brhane et al. (2017), who reported similar effects of potassium application on the harvest index of wheat.

The HI is a valuable measurement for assessing nutrient and dry matter partitioning in crop plants, indicating how efficiently the plant utilizes acquired nutrients for grain production. A higher harvest index suggests a greater partitioning of dry matter into grain.

Table 1: Harvest index of wheat as affected main effects of P and K fertilizers application rates at Kechi during 2023 main cropping season

| P Rates (kg/ha) | HI |
|---|---|
| 0 | 0.224 [c] |
| 10 | 0.406 [b] |
| 20 | 0.490 [a] |
| 30 | 0.444 [a] |
| LSD (0.05) | 0.0312 |
| K Rates (kg/ha) | HI |
| 0 | 0.224 [b] |
| 30 | 0.356 [a] |
| 60 | 0.299 [b] |
| CV (%) | 7.66 |

*LSD (0.05) =Least Significant Difference at 5% level; CV=Coefficient of Variation; Means in column followed by the same letters are not significantly different at 5% level of significance*

## 4.5. Economic Analysis

In this study, the average wheat yield across all tested treatments was adjusted downward by 10%, following CIMMYT (1988) guidelines, to compensate for differences between experimental results and what farmers might expect in the absence of researchers. Using the partial budget procedure outlined by CIMMYT (1988), the total variable cost (TVC) considered the current prices of TSP fertilizer (275 ETB $kg^{-1}$), wheat seed (90.00 ETB $kg^{-1}$), KCl fertilizer (250 ETB $kg^{-1}$), and labor costs for all activities (land preparation, planting, weeding, harvesting, and transportation) across different treatments (Table 4).

The economic analysis revealed that the highest net return of 229815 ETB $ha^{-1}$ was achieved from the wheat produced with combined application of 20 P kg/ha with 30 K kg/ha fertilizer application, with a marginal rate of return (MRR) of 1783.1%. Whereas, the lowest net benefit of 141205.5 ETB $ha^{-1}$ was recorded from 0 P kg/ha with 30 K kg/ha fertilizer application (Table 4). Using the marginal rate of return (MRR %) as a basis for recommendations, the combination 20 P kg/ha with 30 K kg/ha fertilizer application was found to be economically feasible at the study sites and areas with similar agro-ecologies.

Table 2: Profitability of wheat production as affected by P and K fertilizer rates at Kechi during 2023 main cropping season

| P rate (kg/ha) | K rates (kg/ha) | SC (ETB $ha^{-1}$) | TSP ETB $ha^{-1}$) | KCl (ETB $ha^{-1}$) | LC (ETB $ha^{-1}$) | Av. Y(kg/ ha | ADTY(kg/ ha) | GFB (ETB $ha^{-1}$) | TVC (ETB $ha^{-1}$) | NB (ETB $ha^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 5400 | __ | __ | 4950.00 | 610 | 549 | 35685 | 10350 | 25335 | __ |
| | 30 | 5400 | __ | 7500 | 5184.50 | 2740 | 2466 | 160290 | 18084.5 | 141205.5 | 1498.1% |
| 0 | 60 | 5400 | __ | 15000 | 2064.50 | 2390 | 2151 | 139815 | 22464.5 | 114450.5 | D |
| | 0 | 5400 | 2750 | __ | 8048.00 | 2710 | 2439 | 158535 | 14198 | 144337 | -3990.6 |
| | 30 | 5400 | 2750 | 7500 | 6596.00 | 3410 | 3069 | 199485 | 22246 | 177239 | 388.6 |
| 10 | 60 | 5400 | 2750 | 15000 | 7562.50 | 3340 | 3006 | 195390 | 30712.5 | 164677.5 | D |
| | 0 | 5400 | 5500 | __ | 9020.50 | 3230 | 2007 | 130455 | 19920.5 | 110534.5 | D |
| | 30 | 5400 | 5500 | 7500 | 8210.0 | 4350 | 3945 | 256425 | 26610 | 229815 | 1783.1% |
| 20 | 60 | 5400 | 5500 | 15000 | 8315.5 | 4010 | 3609 | 234585 | 34215.5 | 200369.5 | D |
| | 0 | 5400 | 8250 | __ | 7754.5 | 3510 | 3159 | 205335 | 21404.5 | 183930.5 | D |
| | 30 | 5400 | 8250 | 7500 | 8860.5 | 4270 | 3843 | 249795 | 30010.5 | 219784.5 | 416.6% |
| 30 | 60 | 5400 | 8250 | 15000 | 6056.0 | 4190 | 3771 | 245115 | 34706 | 210409 | D |

SC = *Seed cost*; TSP = *Triple super phosphate*; ADY = *adjusted grain yield;* GFB = *gross field benefit*; MRR = *marginal rate of return; LC= Labor cost; TVC = total variable cost*

# 5. SUMMARY AND CONCLUSION

Wheat is the most widely grown cereal crop and staple food in Ethiopia. However, soil nutrient depletion becomes a serious threat to the productivity of wheat in the Kechi area, Dawro zone, south-west Ethiopia. Balanced fertilization with an optimum application rate is necessary to increase the productivity of wheat. In this context, this experiment was conducted at the Kechi farm site of Wolaita Sodo University during the 2023 cropping season with the objective of suggesting the optimum rate of P and K fertilizer for the wheat crop. The experiment comprised four levels of P (0, 10, 20, and 30 kg/ha P) and three levels of K (0, 30, and 60 kg/ha K). It was laid out in a randomized complete block design with a factorial arrangement involving three replications. Data were collected on crop phenology, growth, yield and yield-related parameters. The collected data were subjected to analysis using Statistical Analysis System (SAS) version 9.20 (SAS, 2008).

The result showed that all measured parameters were significantly affected by P and K fertilizer application with different rates. Most of the measured parameters are significantly affected by the interaction of P and K rates, which are phenological, plant height, total tillers, number of seeds per spike, thousand seed weight, above-ground biomass yield, grain, and straw yield. However the productive tillers and harvest index of wheat were significantly influenced only by the main effects of P and K rates. Increasing the rate of P and K shortened the duration of heading and physiological maturity of wheat. On the other hand, growth parameters yield, and yield components increased as the rate of P and K increased, The maximum grain yield (4350 kg/ha) was obtained from where 20 kg/ha P and 30 kg/ha K were applied, while this maximum yield was six fold higher in comparison to the lowest grain yield (649.7 kg/ha) that was obtained from unfertilized plots.

similarly, the partial budget analysis of the studied treatments revealed that the highest net benefit of 229815 ETB $ha^{-1}$ with a marginal return of 1783.1% was attained from the application rate of 20 kg/ha P and 30 kg/ha, while the net benefit of 141205.5 ETB $ha^{-1}$ was attained from the application rate of 0 kg/ha P and 30 kg/ha. Thus, 20 kg/ha P and 30 kg/ha K could tentatively increase wheat productivity and economic profit in the study area and areas with similar agro-ecological. However, the experiment was conducted over a single season at one site; further study across multiple seasons and locations is needed for a more reliable recommendation.

# 6. REFERENCES

Abass Abdu Ali, 2021. Geo-spatial analysis and digital mapping of soil properties for site-specific management of research farms in Wolaita Sodo University, Southern Ethiopia. MSc Thesis postgraduate directorate of Wolaita Sodo University.

Adamu Molla. 2013. Farmers' Knowledge Helps Develop Site Specific Fertilizer Rate Recommendations, Central Highlands of Ethiopia. *World Applied Sciences Journal*, 22 (4): 555-563.

Ahmad. S, N.E. Jan, R. Khan, R. Khan, Faridullah and N. Din. 2010. Wheat response to phosphorus under climatic conditions of Juglote. Pakistan, *Sarhad Journal of Agriculture* 26: 229-233.

Akamine, H., Hossain, M.A., Ishimine, Y., Yogi, K., Hokama, K., Iraha, Y., &Aniya, Y. 2007. Effects of application of N, P and K alone or in combination on growth, yield and curcumin content of turmeric (*Curcuma longa* L.). *Plant Production Science, 10*, 151– 154.10.1626/pps.10.151.

Akram, A., Fatima, M., Ali, S., Jilani, G., Asghar, R. 2007. Growth, yield and nutrients uptake of sorghum in response to integrated phosphorus and potassium management. *Pak. J. Bot.*, 39(4): 1083-1087.

Alam, S.M., S.A. Shah and M. Akhtar. 2003. Varietal difference in wheat yield and phosphorus use efficiency as influenced by method of phosphorus application. *Songklanakarin Journal of Science and Technology*, 25: 175-181.

Alam, S.M., Latif, A. and Iqbal, Z. 2002. Wheat Yield and Phosphorus Use Efficiency as Influenced by Method of Phosphorus and Zinc Application. *Pakistan Journal of Scientific and Industrial Research*, 45, 117-119.

Aleminew, A. and Alemayehu, M., 2020. Soil fertility depletion and its management options under crop production perspectives in Ethiopia: A review. Agricultural Reviews, 41(2), pp.91-105.

Ali, H., S. Ahmad, H. Ali and F.S. Hassan. 2005. Impact of Nitrogen Application on Growth and Yield Productivity of Wheat *(Triticum aestivum* L.). *Journal of Agriculture and Social Science* 1(3):216-218.

Ali, N., Anjum, M.M., Khan, G.R. and Ali, R., 2022. Unraveling wheat grain quality, physiological indices, dry matter accumulation, and attenuating water stress adverse effect via foliar potassium application at different growth stages. Gesunde Pflanzen, 74(1), pp.41-52.

Ali, S., Riaz, A., Mamtaz, S. and Haider, H., 2023. Nutrients and Crop Production. Current Research in Agriculture and Farming, 4(2), pp.1-15.

Anonymous. 1988. Better crops with plant food. PPI, Atlanta, USA, pp. 26.

Asgharipour, M.R., and Heidari, M. 2011. Effect of potassium supply on drought resistance in sorghum: plant growth and macronutrient content. *Pakistan, Journal of Agricultural Science.* 48(3) 197-204

Ashraf, A.H. 1986.Studies on the interactive relationship of two wheat genotypes and NPK application under late sown conditions. M.Sc. (Hons.). Agriculture, Thesis Department of Agronomy University of Agriculture. Faisalabad, Pakistan.

Astatke A, Mamo T, and Paden D, Diedhiou M .2004: Participatory on-farm conservation tillage trails in the Ethiopian highland vertisols: the impact of potassium application on crop yields. Exp. Agric. 40: 369–379.

Bakry, A.B, M.MTawfik, Alice T., Thalooth and El-Karamany M.F. 2017. Some agriculture practices for maximizing wheat production under new reclaimed sandy soil. Research Journal of Pharmaceutical, Biological and Chemical Sciences ISSN: 0975-8585, pp.169-180.

Balesh, T., F. Zapta, J. Aune, and B. Situala. 2005. N fertilization, soil type and cultivars effects on N use efficiency in tef (*Eragrostis tef* (Zucc) Trotter). Nutr. Cycl. Agro ecosystem. 71: 203–211.

Baque, M. A., M. A. Karim, A. Hamid and H. Tetsushi, 2006. Effects of fertilizer potassium on growth, yield and nutrient uptake of wheat (*Triticum aestivum L.*) under water stress conditions. South Pacific Studies, 27(1):25-35

Bashir .S, Anwar. S, Ahmad. B, Sarfraz Q, Khatt. W, Islam. M. 2015. Response of wheat crop to phosphorus levels and application methods. *Journal of Environment and Earth Science*, 5(9) 151-155.

Bekele Geleta, Amanuel Gorfu and Getinet Gebeyahu. 1993. Wheat production and research in Ethiopia constraint and sustainability, pp. 18-25, *In:* D.G. Tanner, (ed).Developing sustainable wheat production systems. The eight regional wheat workshops for Eastern, Central and Southern Africa, Kampala, Uganda. June 7-10.

Belay, A., Mirzabaev, A., Recha, J.W., Oludhe, C., Osano, P.M., Berhane, Z., Olaka, L.A., Tegegne, Y.T., Demissie, T., Mutsami, C. and Solomon, D., 2024. Does climate-smart agriculture improve household income and food security? Evidence from Southern Ethiopia. Environment, development and sustainability, 26(7), pp.16711-16738.

Bellete, T. 2014.Fertility Mapping of Soils of Abay-Chomen District, Western Oromia, Ethiopia. MSc Thesis, Haramaya University, Ethiopia.

Bouyoucos GJ. 1962. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal*, 54(5): 464-465.

Brady, N. and R. Weil. 2002. The Nature and Properties of Soils, 13$^{th}$ Edition. Prentice Hall. Upper Saddle River, New Jersey. 960 p

Brady, N. C., 2002. Phosphorus and Potassium. In: The nature and properties of soils. Prentice Hall of India, Delhi. 352 p.

Braun H-J., G. Atlin and T. Payne 2010. Multi-location testing as a tool to identify plant response to global climate change. In: Climate change and crop production (ed. M.P. Reynolds). CABI International, pp 115-138.

Bremner JM, Mulvaney CS. 1982.Nitrogen-total.Methods of soil analysis. Part2. Chemical and microbiological properties.(Methods of soil an2), 595-624.

Brhan, A, 2012. Agronomic and Economic Effects of Blended Fertilizers under Planting Method on Yield and Yield Components of Tef in Wereda Laelay Maychew, Central Tigray, Ethiopia, MSc thesis, College of Dry Land Agriculture and Natural Resources, Mekelle University, Mekelle, Ethiopia

Brhane H, Mamo T, Teka K. 2017. Potassium Fertilization and its Level on Wheat (*Triticum aestivum*) Yield in Shallow Depth Soils of Northern Ethiopia. *J Fertil Pestic* 8: 182. doi:10.4172/2471-2728.1000182

Brhane, et al. (2017). Impact of Potassium on Wheat Harvest Index.

Busenberg, E. and Clemency C. V. 1973. Determination of the cation exchange capacity of clays and soils using an ammonia electrode. Clays and Clay Minerals 21:213–217.

Cassman, K.G., Doberman, A., Walters, D.T. 2002. Agroecosystems, nitrogen use efficiency, and nitrogen management. Ambio 31, 132-140.

Chapman, F. M and J. L. Mason 1969. Effect of phosphorus and Potassium Fertilizer on the Agronomic Characteristics of Spring Wheat and Their Interaction on Grain Yield. *Canada Journal of Soil Science,* Vol. 49, 343-347.

Chhokar RS, Sharma RK, Chauhan DS and Mongia AD .2006. Evaluation of herbicides against Phalaris minor in wheat in north western Indian lains. Weed Res, 46:40-9.

CIMMYT (International Maize and Wheat Improvement Center). 1988. An Economic Training Manual: from agronomic data recordation. CYMMT, Mexico p: 79.

Craswell, E.T. and P.L.G. Vlek. 2013. Nutrient mining in African soils due to agricultural intensification: In R. Lal and B.A. Stewart, Principles of Sustainable Soil Management in Agroecosystems, Advances in Soil Science pp.401-421.

Crespo-Herrera, Crossa J. and Huerta-Espino J. 2018. Genetic Gains for Grain Yield in CIMMYT's Semi-Arid Wheat Yield Trials Grown in Suboptimal Environments. *Crop science* 58: 1890-1898.

CSA (Central Statistical Agency). 2017. Agricultural Sample Survey Report on area and production of major crops for private peasant holdings, Maher season. Volume I, Statistical Bulletin 584, Addis Ababa, Ethiopia.

CSA (Central Statistical Agency). 2022. The Federal Democratic Republic of Ethiopia Central Statistical Agency Agricultural Sample Survey 2021/22 (2014 E.C.) Volume I Report On Area And Production Of Major Crops.

Curtis, B.C. 2002. Wheat in the World. In: Bread Wheat: Improvement and Production, Curtis, B.C., S. Rajaram and H. Gomez Macpherson (Eds.). Food and Agriculture Organization FAO), Rome: 1-18.

Damene, D. 2003. Yield response of bread wheat (*Triticum aestivum* L.) to applied levels of N and P fertilizers on Nitosols of Dawuro Zone, South Western Ethiopia. M.Sc Thesis, the School of Graduate Studies, Haramaya University, Ethiopia.

David, M.E. and J.T. David. 2012. Modeling an improvement in phosphorus utilization in tropical agriculture. J.

Dixon, J.; Braun, H.J.; Kosina, P.; Crouch, J.H. (eds.). 2009. Wheat Facts and Futures 2009. Mexico, DF (Mexico): CIMMYT, 95 p.

Drechsel, P., Kunze, D. & de Vries, F.P. 2001. Soil Nutrient depletion and population growth in sub-Saharan Africa. Population and Environment 22: 411.

Duivenbooden, N.V. Wit, C.T.D., Keulen, H.V. 1996. Nitrogen, phosphorus and potassium relation in five major cereals reviewed in respect to fertilizer recommendations using simultation modeling. Fertilizer Research 44: 37- 49.

Dvorak, J., Luo, M.-C., Yang, Z. L. & Zhang, H.B. 1998.The structure of the *Aegilops tauschii* gene pool and the evolution of hexaploid wheat. Theor. Appl. Genet., 97: 657-670.

El-Mageed, T.A.A., Semida, W.M., Abdou, N.M. and El-Mageed, S.A.A., 2023. Coupling effects of potassium fertilization rate and application time on growth and grain yield of wheat (Triticum aestivum L.) plants grown under Cd-contaminated saline soil. Journal of Soil Science and Plant Nutrition, 23(1), pp.1070-1084.

EthioSIS (Ethiopian Soil Information System). 2014. Soil fertility mapping and fertilizer blending. Agricultural Transformation Agency (ATA) Report, Ethiopia soil information system (Ethiosis). Ministry of Agriculture, Addis Ababa.

EthioSIS (Ethiopian Soil Information System). 2013. towards improved fertilization in Ethiopia-Nutrient indices for categorization of blends from EthioSIS woreda soil invertery data. A/A, Ethiopia.

EthioSIS (Ethiopian Soil Information System). 2015. http://www.ata.gov.et/highlighted-deliverables/ethiopian-soilinformation-system-ethiosis/.

EthioSIS (Ethiopian Soil Information System). 2016. The Role of DSM in Transforming Agriculture: 7th Global DSM Workshop.

Fageria, N.K., N.A. Slaton, and V. C. Baligar. 2003. Nutrient management for improving lowland rice productivity and sustainability. *Adv. Agron*. 80:63-152.

Fanuel Laekemariam and Kibebew Kibret. 2020. Explaining soil fertility heterogeneity in small holder farmers of Southern Ethiopia. *Applied and Environmental soil since*. 2020:6161059, 16

FAO (Food and Agricultural Organization of the United Nations). 2021. Crop Prospects and Food Situation Quarterly Global Report No. 1, March 2021.Rome.

FAO (Food and Agricultural Organization of the United Nations). 2022. Crop Prospects and Food Situation Quarterly Global Report No. 2, July 2022. Rome.

FAO (Food and Agricultural Organization of the United Nations). 2006. Plant Nutrition for food security: A guide for integrated nutrient management, Fertilizer and Plant Nutrition Bulletin 16.Rome

FAO (Food and Agricultural Organization of the United Nations).1995. Integrated plant nutrition System. In: Dudal R. and Roy, R.N. (Eds.) *FAO Fertilizer and Plant Nutrition*

*Bull. N, 12.Plant* Nutrition Management Service, FAO Land and Water Development Division. Rome, Italy.

FAO (Food and Agriculture Organization) (2015a).Food Balance Sheets. FAOSTAT, Rome.

FAOSTAT (FAO Statistical Databases) 2012. Agricultural Production Statistics.

http://www.fao.org/faostat. Accessed 15 March 2016.

Feyisa, H., Mengistu, G., Biri, A. and Chimdessa, T., 2023. Research Article Grain Yield and Yield Related Traits of Bread Wheat as Influenced by N and Seeding Rates and Their Interaction Effects in 2020 under Irrigation at Western and North of Oromia, Ethiopia.

Nasir, M.A., Nugroho, A.D. and Lakner, Z., 2022. Impact of the Russian–Ukrainian conflict on global food crops. Foods, 11(19), p.2979.

Gebeyehu, T., and T. Mamo. 1999. Forms of Soil Potassium and its Availability for Sugarcane Plant at Wonji Sugar Estate in Ethiopia. Ethiopian Journal of Natural Resources 1(1):17- 28.

Gebreselassie Y. 2002. Selected chemical and physical characteristics of soils research center and its testing sites in North-western Ethiopia. *Ethiopian Journal of Natural Resources*

George, M. S., Lu, G. and Zhou, W. 2002. Genotypic variation for potassium uptake and utilization efficiency in sweet potato (*Ipomoea batatas* L.). Field Crops Res. **77**: 7-15.

Godebo, T., Laekemariam, F. and Loha, G., 2021. Nutrient uptake, use efficiency and productivity of bread wheat (Triticum aestivum L.) as affected by nitrogen and potassium fertilizer in Keddida Gamela Woreda, Southern Ethiopia. Environmental Systems Research, 10(1), p.12.

Grant, C.A., D.N. Flaten and D.J. Tomasiewicz. 2001. Sheppard SC. The importance of early season P nutrition.Can. J. Plant Sci., 81: 211–224.

Grzebisz W., Wrońska M., Diatta J.B., Szczepaniak W. 2008. Effect of zinc foliar application at an early stage of maize growth on patterns of nutrients and dry matter accumulation by the canopy. Part II: Nitrogen uptake and dry matter accumulation patterns. *Journal of Elementology,* 13: 29–39

GU, X., Liu, Y., Li, N., Liu, Y., Zhao, D., Wei, B. and Wen, X., 2021. Effects of the foliar application of potassium fertilizer on the grain protein and dough quality of wheat. Agronomy, 11(9), p.1749.

Guarda, A., Rosell, C. M., Benedito, C., & Galotto, M. J. 2004. Different hydrocolloids as bread improvers and antistaling agents. *Food Hydrocolloids*, *18*(2), 241 247.

Hagos Brhane and Kassa Teka 2018. Optimum K Fertilizer Level for Growth and Yield of Wheat (*Triticum aestivum*) in Cambisols of Northern Ethiopia. *Asian Research Journal of Agriculture.* 8(2): 1-8,

Hagos Brhane, Tekalign Mamo & Kassa Teka. 2017. Optimum potassium fertilization level for growth, yield and nutrient uptake of wheat (*Triticum aestivum* L.) in Vertisols of Northern Ethiopia, *Cogent Food & Agriculture*, 3: 1347022.

Haile Derese, Nigussie Dechassa, and Amsalu Ayana. 2012. Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. *Journal Soil Science and Plant Nutrition 12(3):389-409.*

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D., and Lensschen, JP. 2005. Assessment of soil nutrient depletion and its spatial variability on small holders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, Ecosystems and Environment,* 108 (1), 1–16.

Hailu Hillette, Tekalign Mamo, R. Keskinen, E. Karltun, Heluf Gebrekidan and Taye Bekele. 2015. Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agric & Food Secur 4:19

Hailu, H., Mamo, T. and Keskinen, R., 2017. Response of wheat (Triticum aestivum L.) to phosphorus and potassium fertilization on Vertisols in Ethiopia's central highlands.

Hawkesford, M., W. Horst, T. Kichey, H. Lambers, J. Schjoerring, I.S. Møller, P. White. 2012. Functions of macronutrients. In: Marschner P, ed. Marschner's mineral nutrition of higher plants, 3rd edn. San Diego, Academic Press.

Hossain, M. A. and Humid, A. 2007. Influence of N and P fertilizer application on root growth, leaf photosynthesis and yield performance of groundnut. *Bangladesh Journal Agricultural Research,* 32(3):369-374.

Hussain .N, N. Hyder, N. Ahmad, 2004. Influence of phosphorus application on growth and yield components of wheat cultivar Punjab-96, *Indus J. Plant Sci*. 3(3) 276-279.

Hussain.Z, R. A. Khattak, M. Irshad, Q. Mahmoud, P. An. 2016. Effect of saline irrigation water on the leachability of salts, growth and chemical composition of wheat (*Triticum aestivum* L.) in saline‑sodic soil supplemented with phosphorus and potassium. *Journal of Soil Science and Plant Nutrition.*16 (3), 604-620

Ibrikei, H., J. Ryan, A.C. Ugler, G. Buyuk, B.Cakir, K. Korkmaz, E. Karnez, G. Orgenturk, and O. Konusken. 2005. Maintenance of Phosphorus Fertilizer and Residual Phosphorus Effect on Corn Production. *Nigeria Journal Soil Science*, 2:279-286

International Fertilizer Industry Association (IFA). 1986. The Fertilizer Industry: World Food Supplies and the Environment. UNEP (United Nations Environment Programme),

Paris. Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Ind., Englewood. Cliffs. N.J., USA.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Ind., Englewood. Cliffs. N.J., USA.

Jan, R., 2022. Fate of Potassium in Crop Production.

Jatav, M.K. 2004**.** Effect of Application of Phosphorus, Manganese and Iron on Yield and Nutrient Uptake by Wheat in Inceptisols. PHD Thesis Maharana Pratap University of Agriculture and Technology, Udaipur Rajasthan College of Agriculture, Udaipur

Jiang, Z.Q., C.N. Feng, L.L. Huang, W.S. Guo, X.K. Zhu and Y.X. Peng. 2006. Effects of phosphorus application on dry matter production and phosphorus uptake in wheat. Plant Nut. & Fert. Sci. 12(5): 628-634.

Jones, C. Olson, R and Dinkins, C. 2011. Nutrient uptake timing by crops: to assist with fertilizing decisions. Montana State University, pp 2-8.

Kemmler, G. 1983. Modern Aspects of Wheat Manuring. IPI Bulletin No.1. Wheat. International Potash Institute (IPI), Switzerland.

Khan, F., Siddique, A.B., Shabala, S., Zhou, M. and Zhao, C., 2023. Phosphorus plays key roles in regulating plants' physiological responses to abiotic stresses. Plants, 12(15), p.2861.

Krishnamurphy YL, Shashikala, J.2006. Inhibition of *aflatoxin* $B_1$ production of *Asperigillas flaves*, isolated from soyabean seeds by certain natural plant products. Lett. Appl Microbiol, 43:469-474.

Kubar, M.S., Zhang, Q., Feng, M., Wang, C., Yang, W., Kubar, K.A., Riaz, S., Gul, H., Samoon, H.A., Sun, H. and Xie, Y., 2022. Growth, yield and photosynthetic performance of winter wheat as affected by co-application of nitrogen fertilizer and organic manures. Life, 12(7), p.1000.

Kundu, S. and Nagrajan S. 1996. Distinguishing Characters of Indian Wheat Varies. Research Bulletin No.4, Directorate of Wheat Research, Kernel, India.

Laekemariam, F. 2015. Soil Spatial Variability Analysis, Fertility Mapping and Soil Plant Nutrient Relations in Wolaita Zone, Southern Ethiopia. PhD Dissertation, Haramaya University, Ethiopia.

Laghari, G.M., F.C. Oad, S. D Tunio, A.W. Gandahi, M.H. Siddiqui, A.W. Jagirani and S.M. Oad. 2010. Growth yield and nutrient uptake of various wheat cultivars under different fertilizer regimes. *Sarhad Journal of Agriculture* 26(4): 489-497Landon JR. 1991.

Landon JR. 2014. Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and sub tropics. John Wiley and Sons, New York. P 474.

Langridge, P., Alaux, M., Almeida, N.F., Ammar, K., Baum, M., Bekkaoui, F., Bentley, A.R., Beres, B.L., Berger, B., Braun, H.J. and Brown-Guedira, G., 2022. Meeting the challenges facing wheat production: The strategic research agenda of the Global Wheat Initiative. Agronomy, 12(11), p.2767.

Liakas, V., V. Rauicks and V. Paltanaviius. 2001. Influence of phosphorus and potash fertilizers on germination, tillering and overwintering of winter wheat. Mokslo Darbai. 74:3-12.

Li, C., Zhao, X., Liu, X., Lu, D., Chen, X., Wang, H. and Zhou, J., 2020. Rice and wheat yield and soil potassium changes in response to potassium management in two soil types. Nutrient Cycling in Agroecosystems, 117, pp.121-130.

Loide, V. 2004. About the Effect of the Contents and Ratios of Soil's Available Calcium, Potassium and Magnesium in Liming of Acid Soils. Agron. Res. 2:71-82.

Madar, R., Singh, Y.V., Meena, M.C., Das, T.K., Paramesh, V., Al-Mana, F.A., A. Mattar, M. and O. Elansary, H., 2020. Residue and potassium management strategies to improve crop productivity, potassium mobilization, and assimilation under zero-till maize–wheat cropping system. Agriculture, 10(9), p.401.

Ma Q., Niknam S.R., Turner D.W. 2006. Responses of osmotic adjustment and seed yield of *Brassica napus* and *B. junacea* to soil water deficit at different growth stages. *Australia Journal of Agricultural Resource*, 57: 221-226.

Ma, Q., Bell, R. & Biddulph, B. 2019 .Potassium application alleviates grain sterility and increases yield of wheat in frost-prone Mediterranean-type climate. Plant Soil 434: 203.

Mamo, T. and I. Haque. 1991. Phosphorous status of some Ethiopian soils. II. Forms of and distribution of inorganic phosphates and their relation to available phosphate. Trop. Agric., 68:2-8.

Mamo, T., and I. Haque. 1988. Potassium Status of Some Ethiopian Soils. East African Agric. And Forestry J. 53:123-130.

Mandal, L.N. and S.K. Khan. 1972. Release of phosphorus from insoluble phosphatic materials in acidic low land rice soils. J. Indian Soc. Soil Sci. 20: 19-25.

Mardamootoo, T., Du Preez, C.C. and Barnard, J.H., 2021. Phosphorus management issues for crop production: A review. African Journal of Agricultural Research, 17(7), pp.939-952.

Marschner H. 1986**.** Mineral nutrition of higher plants. Academic Press. Inc. London.

Maurya P, Kumar V, Maurya KK, Kumawat N, Kumar R, Yadav MP. 2014. Effect of potassium application on growth and yield of wheat varieties. The Bioscan. 9(4): 1371-1373.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of the Mehlich 2 extractant. Communications in Soil Science and Plant Analysis, 15, 1409-1416. Doi: 10.1080/00103628409367568

Mekonnen, M. 2014.Fertility Mapping of Soils in Cheha Woreda, Gurage Zone, Southern Ethiopia. MSc Thesis, Haramaya University, Ethiopia.

Melesse, Heila. 2007. Response of bread wheat (*Triticum aestivum* L.) varieties to N and P fertilizer rates. M.Sc. Thesis, Haramaya University, Haramaya Ethiopia.

Mengel, K., Kirby E. A. 2000. Principle of Plant Nutrition. 5$^{th}$ ed., Intl. Potash Inst., Bern Switzerland

MOA (Ministry of Agriculture). 2013. Plant variety release, protection and seed quality control directorate. Issue No.16: 6-18. Addis Ababa, Ethiopia.

Minot, Nicholas, J. Warner, S. Lemma, L. Kasa, A. Gashaw, S. Rashid. 2015. The Wheat Supply Chain in Ethiopia: Patterns, trends, and policy options. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia

Mojid, M.A., G.C.L. Wyseure, S.K. Biswas. 2012. Requirement of nitrogen, phosphorus and potassium fertilizers for wheat cultivation under irrigation by municipal wastewater. *Journal of Soil Science and Plant Nutrition,* 12(4), 655-665

Noonari, S., Kalhoro, S.A., Ali, A., Mahar, A., Raza, S., Ahmed, M., Shah, S.F.A. and Baloch, S.U. 2016.Effect of Different Levels of Phosphorus and Method of Application on the Growth and Yield of Wheat. Natural Science, 8, 305-314

Öborn I., Andrist-Rangel Y., Askekaard M., Grant C.A., Watson C.A., Edwards A.C. 2005. Critical aspects of potassium management in agricultural systems. Soil Use Manage, 21: 102-112.

Olsen SR. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture; Washington.

Pant, H.K. and Reddy, K.R. (2003).Potential internal lodging of phosphorus in a wetland constructed in agricultural land. *Water Res*. 36, 685-701.

Peterson, R.F. 1965.World crops books. Inter science publishers Inc., New York.

Pratt J, A-M. Boisson E. Gout, R. Douce, S. Aubert. 2009. Phosphate (Pi) starvation effect on the cytosolic Pi concentration and Pi exchange across the tonoplast in the plant cells: an in vivo 31P-nuclear magnetic resonance study using methylphosphonate as a Pi analog. *Plant Physiol*.151: 1646-1657.

Rahim, A., A.M. Ranjha, Rahamtullah and E.A. Waraich. 2010. Effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. Soil Environ. 29:15-22.

Rahmatullah K, Ali Raza Gurmani, Akber Hussain Gurmani and M. Sharif Zia, 2007.Effect of potassium application on crop yields under wheat-rice system. *Sarhad, Journal of Agriculture* Vol. 23, No. 2

Rengel, Z. and P.M. Damon. 2008. Crops and Genotypes Differ in Potassium Uptake and Use. Physiol. Plant. 133:624-636.

Rhoades JD. 1982. in methods of soil analysis, Part 2.Second edition (A. L. Page. Miller and D. R. Keeney, Eds). American Society of Agronomy, Madison, U.

Saha PK, Hossain ATAMS, Miah MAM 2010. Effect of Potassium application on wheat (*Triticum aestivum* L.) in old Himalayan Piedmont Plain. *Bangladesh Journal of Agricultural Research* 35:207-216

Salim, N. and Raza, A., 2020. Nutrient use efficiency (NUE) for sustainable wheat production: a review. Journal of Plant Nutrition, 43(2), pp.297-315.

SAS (Statistical Analysis System). 2008. Version 9.0.SAS Institute Inc., Cary, NC, USA.

Sharshar, M.S., and A.Soad El-Said, 2000. Evalution of Some Wheat Cultivars and Lines under Low and High and Inputs. *Journal of Agricultural Science* 25(6):3109-3127.

Shenoy, V and Kalagudi GM. 2005. Enhancing Plant phosphorus use efficiency for sustainable cropping, Biotechnol. Adv.23, 501-513.

Shiferaw, B., Smale, M., Braun, H.J., Duveiller, E., Reynolds, M., Muricho, G. 2013.Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Secur. 5, 291–317.

Singh, D.K. and P.W.G. Sale. 2000. Growth and potentially conductivity of white clover roots in dry soil with increasing phosphorus supply and defoliation frequency. *Agronomy Journal* 92: 868-874.

Sikandar, M.A., Anjum, S., Idrees, A., Ali, H., Farooq, M.U. and Ismail, I., 2024. Economic analysis of wheat production in district Layyah Punjab, Pakistan. Remittances Review, 9(1), pp.2840-2855.

Slaton, N., R.E. DeLong, M. Mozaffari, S. Clark, C. Allen, and R. Thompson. 2007. Wheat Grain Yield Response to Phosphorus and Potassium Fertilizer Rate. AAES Research series 558 Wayne E. Sabbe Arkansas Soil Fertility Studies.

Tadesse, W., Zegeye, H., Debele, T., Kassa, D., Shiferaw, W., Solomon, T., Negash, T., Geleta, N., Bishaw, Z. and Assefa, S., 2022. Wheat production and breeding in Ethiopia: retrospect and prospects. Crop Breeding, Genetics and Genomics, 4(3).

Tan, Z.X., R.al and K.D. Wiebe. 2005. Global soil nutrient depletion and yield reduction. *Journal Sustainable Agriculture*.26 (1):123-146.

Tang, C., Hinsinger, P., Drevon, J.J., and Jaillard, B. 2001. Phosphorus deficiency impairs early nodule functioning and enhances proton release in roots of *Medicago truncatula* L. *Annals of Botany*, 88: 131-138.

Tariq, M., Saeed, A., Nisar, M., Mian, I. A., & Afzal, M. 2011. Effect of potassium rates and sources on the growth performance and on chloride accumulation of maize in two different textured soils of Haripur, Hazara division. *Sarhad Journal of Agriculture, 27*, 415–422.

Tekalign Mamo, I. Haque and E.A. Aduyi. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant science division working document 13, ILCA, Addis Ababa, Ethiopia.

Tesfaye, T., Laekemariam, F. and Habte, A., 2021. Response of bread wheat (Triticum aestivum L.) to potassium (K) and blended NPS fertilizer rates in the nitisols of Southern Ethiopia. *Applied and Environmental Soil Science, 2021*(1), p.8868940.

USDA Foreign Agricultural Service. (2022). Grain and Feed Annual - Ethiopia. Retrieved from USDA Foreign Agricultural Service.

Tirfi, A.G. and Oyekale, A.S., 2022. Impact of climate change on yields of wheat in Ethiopia: An augmented Cobb-Douglas production function approach. Journal of Agricultural, Food and Environmental Sciences, JAFES, 76(1), pp.34-47.

Van Beek, C. L. E. Elias, G. S. Yihenew, H. Heesmans. A. Tsegaye H., Feyisa M., Tolla M., Melmuye Y., Gebremeskel S., Mengist. 2016. Soil nutrient balances under diverse agro-ecological settings in Ethiopia. Nutr Cycl Agroecosyst.

Walkley A, Black IA 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 37(1): 29-38.

Wang, J., Luo, M.C., Chen, Z., You, F.M., Wei, Y., Zheng, Y., 2013. Aegilops tauschii single nucleotide polymorphisms shed light on the origins of wheat D-genome genetic diversity and pinpoint the geographic origin of hexaploid wheat. New Phytol. 198 (3), 925–937.

Wang, J., Qin, Q., Pan, J., Sun, L., Sun, Y., Xue, Y. and Song, K., 2019. Transcriptome analysis in roots and leaves of wheat seedlings in response to low-phosphorus stress. Scientific Reports, 9(1), p.19802.

Wassie Haile and Tekalign Mamo, 2013.The effect of potassium on the yields of potato and wheat grown on the acidic soils of Chencha and Hagere Selam in Southern Ethiopia. In: International Potash Institute, e-ifc No. 35; 3-8.

World Book Encyclopedia, 1993. World book-Child craft International.Vol.20

Yawson, D. O., Kwakye, F. A., Armah and K.A. Frimpong. 2011. The dynamics of potassium (K) in representative soil series of Ghana. *Journal of Agricultural and Biological Science*, 6(1): 48-55.

Yishak Beyene. 2021. Phosphors sorption and response of selected soil properties to lime rates at research –farms of Wolaita Sodo University, Southern Ethiopia. MSc Thesis post graduate directorate of Wolaita Sodo University.

Zarcinas, B.A, B. Cartwright, and Spouncer, L.R. 1987. Nitric Acid Digestion and Multi-Element Analysis of Plant Material by Inductively Coupled Plasma Spectrometry. Communications in Soil Science and plant Analysis 18(1):131-146.

Zhang, M.D., X.L. Chun and C.L. Li. 1999. Signs of phosphate shortage in wheat and the benefits of fertilizers. J. Henan Agric. Sci. 11: 27-28.

# 7. APPENDICES

Appendix Table 1. Mean square of ANOVA for day to heading, day to physiological maturity, and plant height of wheat at Kechi during 2023 main cropping season

| Source | DF | Days to heading | Days to Maturity | Plant height |
|---|---|---|---|---|
| Rep | 2 | 0.1719 | 12.751 | 0.654 |
| P | 3 | 20.4684* | 79.320* | 587.410* |
| K | 2 | 72.3336* | 125.284* | 605.810* |
| P*K | 6 | 6.3784* | 29.603* | 150.021* |
| Error | 22 | 1.8619 | 10.891 | 2.866 |

**=significant at 0.05 probability level, DF=Degree of freedom*

Appendix Table 2. Mean squares of ANOVA for number of total tillers, number of productive tillers, grains per spike and 1000 seed weight of wheat at Kechi during 2023 main cropping season

| Source of variance | DF | Total tiller number | No. of Productive tillers | Grains per Spike | 1000 Seed Weight |
|---|---|---|---|---|---|
| REP | 2 | 3930.2 | 434.7 | 2.14 | 13.8 |
| P | 3 | 76102.2* | 1758.2* | 151.08* | 183.683* |
| K | 2 | 40426.6* | 2237.0* | 1210.38* | 527.9* |
| P*K | 6 | 2025.5 * | 12339.3$^{ns}$ | 104.07* | 13.7* |
| Error | 22 | 772.8 | 450.4 | 16.73 | 2.856 |

**=significant at 0.05 probability level, ns=not* significant, DF=Degree of freedom*

Appendix Table 3. Mean squares of ANOVA for above ground dry biomass, grain yield, straw yield, and harvest index of wheat at Kechi during 2023 main cropping season

| Source of variance | DF | Above ground Biomass yield | Grain Yield | Straw yield | Harvest Index |
|---|---|---|---|---|---|
| **REP** | 2 | 31306.0 | 421 | 38190 | 0.00032 |
| **P** | 3 | 1.065E+07* | 9146925* | 418593* | 0.07148* |
| **K** | 2 | 1.840E+07* | 4457661* | 7698424* | 0.02890* |
| **P*K** | 6 | 5116730* | 618811 * | 2314986* | 0.00227$^{ns}$ |
| **Error** | 22 | 17170.9 | 35804 | 73437 | 0.00102 |

**=significant at 0.05 probability level, ns=not* significant, DF=Degree of freedom*

# BIOGRAPHICAL SKECH

The author was born on March 15, 1998, G.C., to his father Bezula Feleho and his mother Worknesh Shibru in Esera Woreda, Dawro Zone, South West Ethiopia region. From 2005 until 2011, G.C., he attended primary education at Ofa Elementary School. He then continued his education at Esera Bale Senior Secondary and Preparatory School from 2012 to 2016 G.C. After passing the Ethiopian university entrance examination, he enrolled at Wolaita Sodo University in 2017 G.C., where he pursued a bachelor's degree in plant science and graduated with great distinction in July 2019 G.C. Upon graduation, he was employed as a graduate assistant at Wolaita Sodo University in September 2020. After serving the university for two consecutive years, he joined Hawassa University in October 2022 to pursue a Master of Science Degree in Agronomy.