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POTATO (*Solanum tuberosum* L.) RESPONSE TO CROP RESIDUES AND VARYING COMBINATIONS OF INORGANIC POTASSIUM FERTILIZER IN WOLAITA, SOUTH ETHIOPIA

Abebe E[1, 2*], Wassie H[1] and K Alemayehu[1]

Endale Abebe

*Corresponding author email: endaleabebe192@yahoo.com
ORCID: https://orcid.org/0009-0007-0183-1374 - Abebe E
ORCID: https://orcid.org/0000-0003-2352-3720 - Wassie H
ORCID: https://orcid.org/0000-0002-9227-3289 - Alemayehu K

[1]Hawassa University, College of Agriculture, School of Plant Science and Horticulture, Ethiopia

[2]Wolaita Soddo University, College of Agriculture, Department of Plant Science

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ABSTRACT

Emerging research evidence indicates that Potassium (K) is a limiting nutrient in Ethiopian soils. However, its fertilizer is costly and rarely available, especially in communities facing severe poverty. As a result, the researcher looked for locally available organic sources of potassium in the areas. Field experiments were conducted on potato crops to identify the best optimum and optional potassium fertilizer (KF) sources in soils from two sites representing areas where potassium deficiency had been previously identified by studies from the Ethiopian soil information system (Ehiosis). Treatments included residues and mixes with fixed rates as KF sources (organic and inorganic); these are 100 % optimum potassium chloride (KCl) standardized by previous research and used as check, potato residue (PR) equivalent of optimum KCl, PR equivalent of 75 % optimum KCl, PR equivalent of 125 % optimum KCl, PR of 50 % combined with 50% of KCl, PR of 25% combined with75 % of KCl, PR of 75 % combined with 25 % of KCl, PR of 50% combined with coffee husk (CH) of 50 % to optimum KCl and CH of 50 % combined with 50 % of KCl laid in RCBD (randomized complete block design). The previously identified research optimum standards were 150 kg ha^{-1} and 120 kg ha^{-1} KCl for Abota-ulto and Gututo-ampokoysha sites respectively. Results showed difference in both treatments and locations. The highest marketable tuber yield (MTY, 30.99 tha^{-1}) and total tuber yield (TTY, 35.4 tha^{-1}) were obtained from the combined application of PR equivalent to 50% of optimum KCl and 50% of KCl, which resulted in a 33.5% and 30% yield advantage over the lowest yield, respectively. Total tuber number per plot (TTNPP) and average tuber weight (Av.TW) also showed superior results with the same application. Plant height, total dry biomass, and specific gravity showed inconsistent trends among treatments. Locational yield and yield components were higher at Abota-ulto than Gututo-ampokoysha. Partial budget analyses indicated that the highest net benefit and acceptable marginal rates of return were achieved at Abota-ulto (107.4%) and at Gututo-ampokoysha site (168.38%) with the highest net benefit also resulting from the application of 50% PR with 50% KCl and this treatment was identified optimum. Finally, potato residue has been found to have greater nutrient potential. A balanced combination of PR with KCl has been identified as the best integration, and has been selected as the optional K-source over the CH combinations.

Key words: Potassium fertilizer, Potato production, Marketable yield, Economic feasibility

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INTRODUCTION

Agriculture is basic for sustainable development, poverty reduction, and food security in developing countries like Ethiopia. Root crops are a good source of food, cash and foreign exchange for the growers and; good cereal import substitutes in Ethiopia [1]. Among root crops, potato is a highly recommended food security crop that can safeguard low-income countries from the risks posed by rising international food prices [2, 3].

Irish potato (*Solanum tuberosum, L.*) belongs to the Solanaceae family and is known worldwide for its high consumption among root crops, ranking second only to cereals [4]. However, in the major potato-producing areas of Ethiopia, the average yield (less than 10 t ha^{-1}) is low due to inappropriate fertilizer applications, leading to widespread undernourishment in the community.

Though potato is a nutrient-demanding crop, it grows well on soil with an average of 2.5 g/kg nitrogen (N), 30 mg/kg phosphorus (P) and 0.2 mol/kg potassium (K) in African highlands [5]. Moreover, fertilizer application has important effects on the quality and yield of potato [6]. Potassium (K) is an essential nutrient for crop production and fulfills a number of important roles in plant growth [7]. The research done in Pakistan showed that tuber yield was increased with increasing rate of potassium fertilizer and the maximum potato tuber yield (34.05 t ha^{-1}) was reported where 139 kg K ha^{-1} was applied and further increase in K application rate could not bring about any significant change in potato tuber yield [8]. In the same manner the soil K levels around, Hagere Selam, Southern Ethiopia found that K applied at 100 kg ha^{-1} in the form of KCl increased the total and marketable tuber yields by 208 and 252 % over the control [9]. Potassium is also considered a potentially limiting nutrient for supporting optimal crop growth in the Alfisols of the neighboring district to Hagere Selam [10]. The research done in northern parts of Ethiopia, particularly Tigray region, Atsbi-Wenberta area, showed that there was a significant difference in total tuber yields with the increase in application rate of K.

Response to K^+ uptake by crops depends to a considerable extent on the level of N nutrition and, also stimulated by P- uptake as well due to synergism of opposite charged ions for full development of potato [11]. That is why the researcher understood their significances and carefully used nationally recommended amount of P fertilizers after checking the compositions of residues. The vital problems of the study were that, the inorganic K fertilizers are not yet recommended due to inaccessibility in the country, and the general understanding, that Ethiopian soils are rich in K and there was no need for its application based on the research concluded some 40 years ago by Murphy [12]. However, with time it is likely that in some soils, deficiency of K could occur due to continuous mining, leaching loss; and soil erosion

[13]. Moreover, if farmers cannot afford KCl fertilizer due to high costs, its use in Ethiopia, particularly among Wolaita farmers, is inefficient. This is because of a lack of credit, the risk of crop failure, and the fact that farmers in the study areas do not actually practice methods to increase soil potassium. These fertilizer input problems led the researcher to look for locally available organic potassium sources, such as potato residue (PR) and coffee husks, which are crucial for enhancing crop yields at minimal costs and without adverse effects on the environment [14].

Potato residues have significant nutrient potential, with an average quantity of primary nutrients (N, P, and K) in kg per hectare. However, these residues are often discarded in study areas due to a lack of knowledge and experimentation, despite their environmental benefits. Utilizing these resources is essential for maintaining environmental health, such as avoiding the long-term use of only inorganic fertilizers in soils [15]. Various organic potassium sources were considered, including crop by-products, potato residue biomass, and a blend of common coffee husks, as agricultural by-products release nutrients in varying amounts. Potato residue and coffee husks were estimated to provide ample potassium release [16,17].

The untimely and unfair supply of synthetic fertilizers, along with rising costs, presents a significant challenge for farmers, leading to food shortages in Wolaita areas where food aid is still needed. These economic burdens motivated the researcher to explore organic alternatives to enhance potato productivity and reduce dependency on expensive imported chemical fertilizers. Adopting sustainable soil fertility management strategies is crucial, as previous research has mainly focused on inorganic potassium fertilizers. Additionally, returning crop residue to the soil can help avoid greenhouse gas emissions caused by burning it, while improving soil organic matter content, physical properties, water use efficiency (WUE), and soil structural stability [18,19].

Farmers in the Wolaita area suffer from food shortages year after year, producing less than10 t ha^{-1} for potatoes and even less for other crops due to a lack of knowledge on optional soil fertilizers to boost productivity. Therefore, using residues as soil inputs at minimal cost and supplementing them with chemical fertilizers, when necessary, is vital for smallholder farmers to make cost-effective soil nutrient amendments [20]. Thus, the objective of the research was to select proportionally equivalent and optimum amount of potassium chloride, coffee husk and/or potato residue or mixes of them by evaluations on yields of potato. The residues or combinations of them can be replaced either totally or partially in integration with costly and rarely available inorganic KCl fertilizer as specific to the soils of two climatically different sites of Wolaita area.

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MATERIALS AND METHODS

Characteristics of the experimental sites

The two sites selected for study and recommended for potassium deficiencies on their soils by Ethiopian soil information system (Ehiosis) [21].

Abota-ulto site is geographically located between 07°02'33" and 07°03'43" N, and 037°87'80" and 037°90'01" E. Its mean monthly minimum and maximum temperature are 16.27 and 21.68°C, respectively, and receives mean annual rainfall of 1403.94 mm Fig. 1.

Gututo-amphokoysha site is located between 06° 72' 02" and 06° 76' 18" N, and 37° 77'10" and 37° 77'79" E. Mean monthly minimum and maximum temperatures are 19.4°C and 22.5°C, respectively, and receives a mean annual rainfall of 1267.5mm, Fig. 2.

Pre-planting soil analyses

The Abota-ulto site's soil has textural class of clay-loam, with (pH of 5.62) moderately acidic, with moderate total nitrogen (TN=0.22) and very-low available phosphorus (Av P= 5.75 mg kg^{-1}), Table 3 [22, 23]. The Gututo-amphokoysha site's soil has textural class of clay-loam, with pH of 5.08 strongly acidic, with moderate total nitrogen (TN=0.24) and very-low available phosphorus (Av P=2.13mg kg^{-1}) Table 3 [22, 23].

The six years climatic data classify the agro-ecology of Abota-ulto site: wet mid-highland and that of Gututo-ampokoysha is moist mid highland according to classifications of Ethiopian Ecological Zones [24]. Apart from amount/size of rainfall variation, the season and patterns of rain at both sites is the same at every year. That is the climate of Gututo-ampokoysha is relatively hot and that of Abota-ulto is cold Figs 1 and 2.

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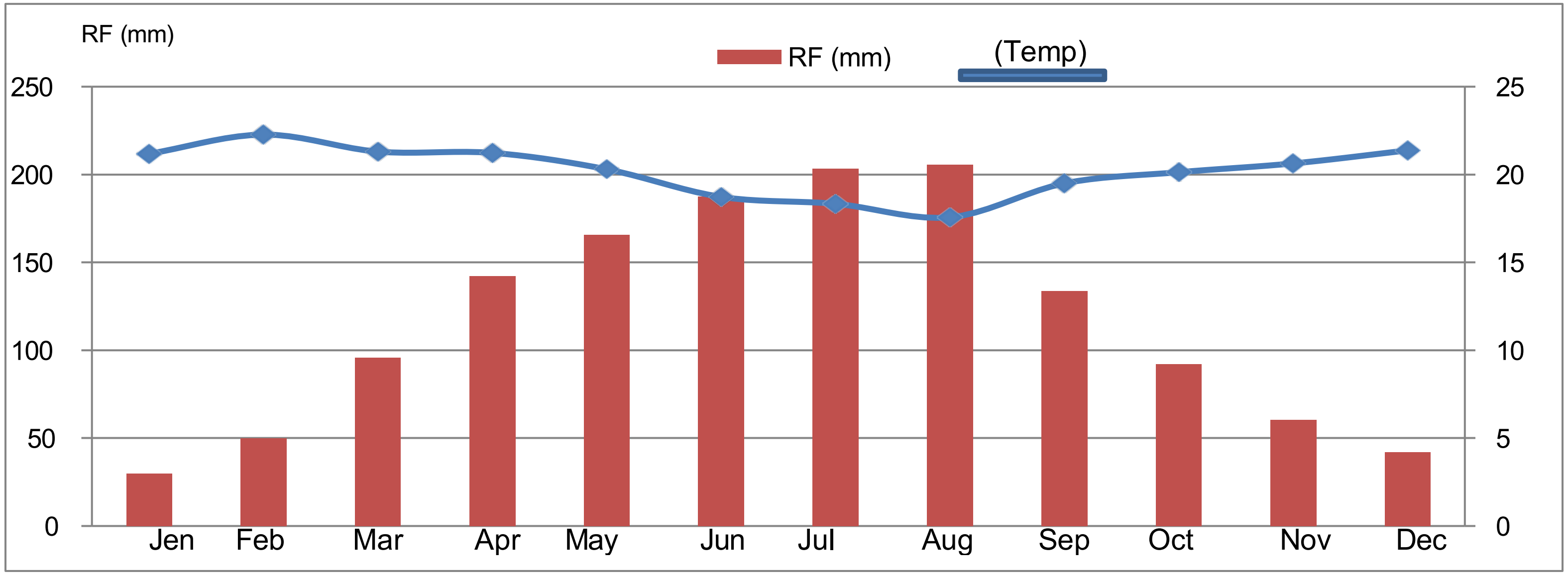

Figure 1: Graph of six years (2017-2022) climatic data (RF and T°) of Abota-ulto Site

Source: National Meteorological Agency, 2022

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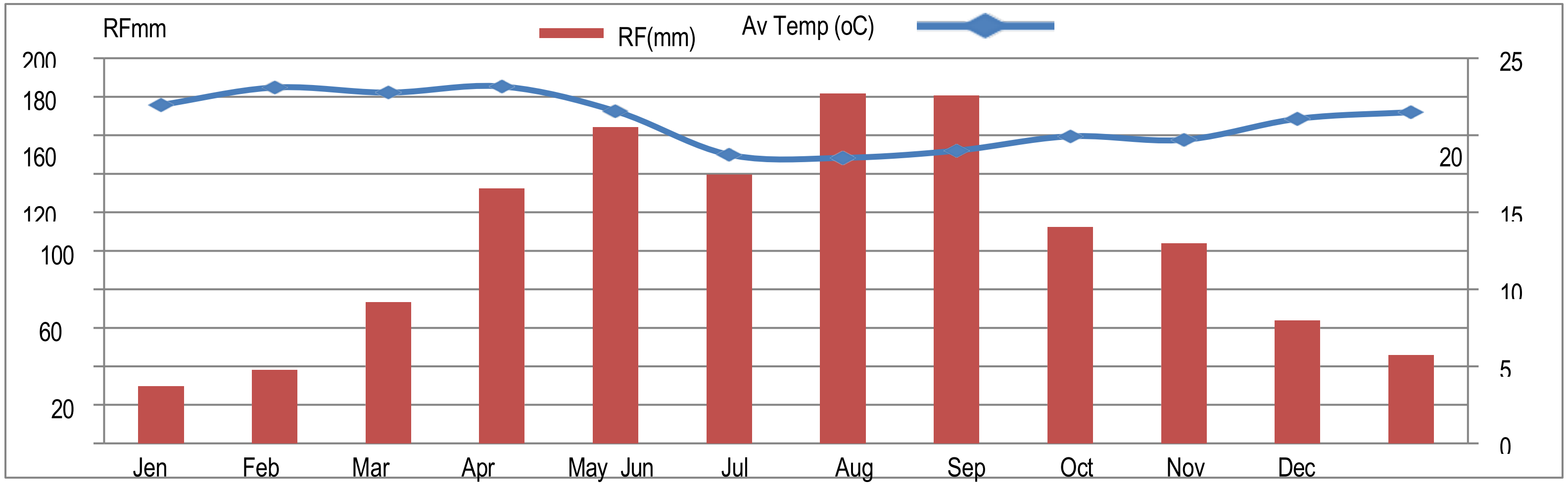

Figure 2: Graph of six years (2017-2022) climatic data of (RF and T°); Gututo-ampokoysha
Source: National Meteorological Agency, 2022. Treatments, design and experimental procedures

Potato Gudane variety was planted in a plot size 2.1 x 3.75m with intra and inter - row spacing of 30 and 70 cm, respectively; in 2023 and 2024, the main potato planting seasons. Plots were separated by 0.5 m within blocks and consecutive blocks were separated by 1 m distance. The residue samples were sun-dried, chopped and grounded to pass through 2mm sieve, and carefully measured with equivalences of K.

Potato residue and combinations of it with KCl and CH as sources of K- fertilizer were standardized by site's respective KCl optimum (100 %) of previous findings. These were KCl- 150 kg ha^{-1} for Abota-ulto and 120 kg ha^{-1} for Gututo-ampokoysha (Table 1). All treatments offered on the bases of 100 % optimum KCl. The estimated equivalents of potato residues were; 100 % PR, 75% PR and 125 % PR were three purely PR treatments. The next estimated equivalents of combined treatments were: 50% of PR with 50% of optimum KCl, 25 % of PR with 75% of KCl, 75% of PR with 25 % of KCl, 50 % PR with 50 % of CH and 50% of CH with 50% of KCl were five combination treatments. The previously optimum sole 100 % KCl was used as fixed check Table 1. The treatments were laid out in randomized complete block design (RCBD) design with three replications

Materials

Potato: Gudane variety was selected by the researcher among other improved varieties (Belete, Jalene and Gudane) in Wolaita area because of its superior performance in productivity on previous researches and better adaptability at wide ranges of ecology including Wolaita area [25]. Moreover, as the researcher made preliminary survey on specific study sites and researches done at Guji area southern Ethiopia, the Gudenie variety was better adapted to Guji highlands. This may be attributed due to inherent genetic differences of the varieties, and hence, evaluated by research centers and distributed to farmers for more versatility than Jalane and Belete varieties in the area [26].

Coffee husk (CH): The southern Ethiopia region and the Wolaita area are coffee production and CH is locally available bulk bio-product. Among coffee bio-products (husks) dry common coffee husk being adopted as input for entire experiments because it is relatively better for handling and managements than others, compositionally, 300 kg K_2O and 160 kg N are obtained from applications of 10826 kg coffee husk per hectare Table 2.

Potato residue (PR): It has nutrient potential of NPK content in its bio-mass of 2.44 t ha^{-1} is 59, 6 and 61 kg ha^{-1} respectively were left back into the soil after harvest according to Torma *et al.* [17] (Table 7). The field experiments made to measure total root biomass ranged from 13 to 96 and 28 to 40 g dry matter (DM) m^{-2} for potato and sugar beet, respectively. However, on the average total root biomass for potato and sugar beet were similar with about 35 g DM m^{-2}. Considering only roots in the topsoil layer the values were lower for sugar beet but most appropriate because potato is known as a shallow-rooted crop with most of its root biomass concentrated in the upper 20 to 30 cm soil layer [25]. Based on above information, the researcher used the average relationship above ground (AG) crop residue (0.32*AY) for average yield used in International Potato Cultivation Center (IPCC) (2006) are 0.04 ±0.279 [27]. In this regard, estimating the above ground bio-mass of potato in the sites, which depended on actual average potato tuber yield produced at two sites was 2910.5kg ha^{-1}=2.9105 $Mgha^{-1}$, and the equation (AY +0.279) used for residue estimations:

1. (2.9105 +0.279) = 3.1895Mg ha^{-1} to convert into gram bases for calculations: multiplied by 1,000,000; giving AY=3,189,500 g ha^{-1}
2. 0.32*average yield =0.32*3,189,500 g ha^{-1}; =1, 020640 AG equation.
3. 1,020,640 ha^{-1}= 1,020640/10,000=102.064 g m^{-2}
4. To convert gram per meter into kilogram per hectare, multiplied by ten and *1020.64 kg ha⁻¹* amount of above ground potato residue was generated after potato cultivations [29].

For below ground residue, as models computed directly adopted 35 g m^{-2} and in hectare bases; 35 g m^{-2} it multiplied by ten *350 kg ha^{-1}* amount of below ground potato residue biomass was generated after potato cultivations [30]. Thus, totally 1020.64+350= *1370.64 kg ha^{-1}* potato residue biomass was potentially harvested. Therefore, this amount of PR has the potential to release nutrients containing 33.14 kg of nitrogen, 3.37 kg of phosphorus, and 34.266 kg of potassium per hectare Torma *et al.* [17].

Data collection and measurements

Data on plant height (PH), total dry bio-mass (DBs), total number of tubers per plot (NTPP), average tuber weight per tuber (Av.TW) and specific gravity (Spr) were taken and recorded. At physiological maturity of the test crop, the data on marketable tuber yield (MTY), unmarketable tuber yield (UMTY) and total tuber yield (TTY) were also collected and recorded. Total tuber yield TTY in kg per plot was collected from middle three rows in each plot and tuber yields from each plot was weighed in 25 kg capacity balance and were graded into three groups for physical quality parameters based on the size of the tuber such as <35 gm (small), 35-55 gm (medium) and >55 gm (large) [29]. Then the TTY of each plot was sorted into MTY and UMTY, weighed and recorded in kg per plot.

The specific gravity was determined according to Kleinkopf *et al.* [30]:

SG =Wa/ Wa –Ww
Where, SG= Specific gravity (g cm-3)
Wa= Weight (g) in the air
Ww= Weight (g) in water

The tuber yields were free from damage by diseases and insect pests, and weighed equal or greater than 25 g were sorted as MTY. Those tuber yields which were rotten/damaged by diseases and insect pests and weighed 25 g were considered as UMTY. Finally, the various components of tuber yield data collected from each plot were converted from kg per plot into metric tons per hectare (m t ha^{-1}) for purpose of analysis and reporting. In addition, tabular and graphical presentations are included when necessary.

Statistical data analysis
The data of yield and yield component parameters were subjected to ANOVA using statistical analysis software (SAS) version 9.0. For those parameters whose ANOVA tested significant, further mean separation was done using Duncan Multiple Range Test (DMRT), syntax on the same software.

Partial budget analyses of treatment effects
Agricultural activities primarily aim to meet the needs of the farmer and their families. These needs could be fulfilled directly using the harvested crop from the farmland or revenue acquired from the crop's sale [31]. For applications, Partial budget analyses (PBA) of treatment effects were done following procedures described in CIMMYT to calculate the economic feasibility of treatments of residues and mixed K- sources for potato production in the study areas (*CIMMYT* [28]. In doing so, mean marketable tuber yield of potato obtained was used after the data were adjusted down by 10 % to compensate for crop management practice differences which are employed by researchers at both sites.

The variables (inputs and labor) cost which is the price of K-fertilizer was taken to be Ethiopian Birr (ETB) KCl=40.00 kg^{-1}, CH=0.5 ETB kg^{-1} and PR=0.4 ETB kg^{-1} plus the labor at a time, it was not much labor intensive (so cheap) which the power estimated and used was (ETB) 0.3 kg^{-1} for KCl, 0.1 kg^{-1} for PR and 0.09 kg^{-1} for CH applications. Accordingly, at the time of crop harvest, prices of potato tuber yield in the local markets of Abota-ulto and Gututo-ampokosha were ETB of 30.0 and 28.0 kg^{-1} for a kilogram of tuber yield, respectively. Gross benefit (GBT) from each treatment was calculated as a product of mean marketable tuber yield (kg ha^{-1})* market price of tuber yield (ETBkg^{-1}). Net benefit (NBT) is calculated as difference between gross benefit of treatment (GBT) and the variable cost (VC) of each treatment. Marginal rate of return (MRR) was calculated as the ratio of the difference between NBTS of successive treatments after sorting data by total variable cost from smallest to largest and the difference between the variable costs of corresponding successive treatment and was expressed in percent. Treatments with MRR values greater than 100 % were considered as economically feasible.

RESULTS AND DISCUSSION

Selected soil physico-chemical properties at the experimental sites before planting

The soil reaction (pH) values were in acidic range in both sites based on the ratings as described by Darmawan *et al.* [31]. The organic carbon (OC) and total nitrogen (TN) contents were in medium category at Abota-ulto site and in the low category at Gututo-ampokosha as per the ratings described by IPCC [27]. In both locations the Average P contents were below soil critical P level established for some Ethiopian soils which is 8.0mg-kg^{-1} [23]. The exchangeable K contents of soils at both sites were found to be below critical level as required for optimum growth and production of potato rated as low (< 0.5, moderate 0.5-0.8, and high >2 cmol kg^{-1} soil) [32]. Thus, as the initial soil K level was lower than critical, especially at Abota-ulto, it resulted in better yield responses than Gututo-ampokoysha site, as shown in Tables 3 and 5 [8].

Effects of types and rates of K-fertilizer sources on yield components and yield of potato

Effects of K-fertilizer sources

Plant height (PH) significantly varied depending on the type of K-fertilizer source used across different sites. The only exception was the lowest plant height observed in the treatment that received PR of 125%, while all other treatments were statistically similar and superior (Table 4). Plant height (PH) was notably higher for all residues mixed with potassium chloride (KCl) fertilizer, which was attributed to the release of nutrients from the residues and the rapid dissolution of KCl in soil water, as suggested by Tekalign and Haque [33]. Total dry biomass (root and shoot) was also influenced by the treatments across the sites. The highest results were observed in the check, sole 100% optimum KCl, and PR of 50% combined with 50% KCl. Conversely, treatments that received PR of 100% and PR of 75% recorded the lowest results (Table 4). These findings support the idea that adequate K-fertilizer application leads to increased leaf area and plant height [34].

The number of tubers per plot was significantly affected by types of treatments over the locations. The lowest and the highest TNPP were recorded from PR of 25 % combined with 75 % of KCl and PR of 50 % combined with 50 % KCl, respectively.

Tuber number per plot (TNPP) was also significantly affected by location. The higher TNPP was obtained at Abota-ulto than Gututo-ampokosha Table 4. This could be due to crop yields being related to physical properties of the soil, as they affect growth differently depending on the crop [28]. Moreover, in related studies based on Meta data analysis; there is wide spatial variation and soil properties variation across different land use in parts of southern Ethiopia including Wolaita area, observed variations enhance different soil fertility management based on their nutrient's potential according to Francis *et al.* [35].

The other yield component parameter was average tuber weight. It recorded significantly superior on treatments that received a mix of PR of 50 % combined with 50 % of KCl. The lowest were from two treatments received mix of CH of 50 % combined with 50 % KCl and mix of PR of 50 % with 50 % CH Table 4. The superiority may be due to the complementary effects of the higher nutrient potential of potato residue in releasing primary nutrients, especially potassium, and the fast solubility of potassium chloride. This contributed to a higher average weight than that of coffee husks [36].

Average TW is one of the most important yield components of potato. Significantly higher Av.TW of potato was obtained at Abota-ulto than Gututo-ampokosha location Table 4. This was soil's response to lower initial available K status of Abota-ulto soil as compared to soils of Gututo-ampokoysha site. The response also related to 'the law of the minimum' that plant growth is controlled not by the total amount of nutrients available but by the amount of the scarcest nutrient as stated by Sprengel [37].

In terms of the effects of treatments and locations on the specific gravity (Spr) of potatoes, treatments that received PR of 125% and PR of 75% combined with 25% KCl yielded the highest results, with respective values of 1.08% and 1.077%. The lowest specific gravity values, 1.068% and 1.069%, were observed in treatments that received 100% optimum KCl and CH of 50% combined with 50% KCl, respectively Table 4. The values were in between and in agreement with those observed by other studies with Spr range of 1.061-1.096 in three Ethiopian potato varieties [37]. The highest results of Spr of treatments applied with PR of 100 % and PR 75 % combined with 25 % KCl were might due to better nutrient release of PR and its mixes with inorganic KCl were mutually contributed as rapid dissolution of KCl in soil water [33].

Effects of fertilizer treatments on tuber yield of potato

Marketable tuber yield (MTY), Unmarketable tuber yield (UMTY) and Total tuber yield (TTY) were significantly affected by main effects of (treatments) types of K-fertilizer sources across sites Table 6. Significantly, the highest total tuber yield (TTY) of 35.4 t ha^{-1} and marketable tuber yield (MTY) of 30.99 t ha^{-1} were obtained

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from the treatment that received 50% of PR combined with 50% inorganic potassium chloride (KCl). Conversely, the lowest TTY of 24.78 t ha^{-1} and MTY of 20.6 t ha^{-1} were obtained from the treatment that received 50% PR combined with 50% of CH (Table 5). This yield difference supports existing literature, which suggests that the source of potassium, whether organic or inorganic, has a significant effect on tuber yield and quality [34]. Importantly, the reason also could be when looking for inorganic sources, it is presumed that KCl fertilization leads to a higher plant osmotic potential, compared to K_2SO_4 and KNO_3 resulting in greater water uptake and vegetative growth, and an increase in competition for assimilates between shoot and tuber, as the shoot is a strong sink for assimilates [38]. As organic sources, potato residue contains higher amounts of potassium than N and P compared to cereals and legumes (Table 7) [17].

The treatment combination of potato residue of 50 % to optimum KCl equivalent with 50 % of inorganic optimum KCl increased MTY and TTY of potato by 33.5 and 30 %, respectively over the lowest treatment that received potato residue of 50 % to optimum KCl equivalent combined with CH of 50 % to optimum KCl equivalent across sites. This gained the total yield advantage of 4.2 t ha^{-1} over even the optimum check, sole 100 % KCl, as shown in Fig 3,4 and Table 5. The results of similar studies reported and indicated that application of K fertilizer significantly increased the tuber yield of potato in Chencha district, southern Ethiopia [5, 39]. The results of the current study also revealed that, the level of exchangeable K content was insufficient and the crop responded more per given K- fertilizer sources in soils at both sites, especially Abota-ulto (Table 3). This is related to research treatments done in the fields of Prince Edward Island farmers where incorporating manure into its residues increased total potato yield by 28 % [17]. The treatment standardized as half-half combined amount of KCl and PR improved the production of potato on both locations were also related to timely solubility of KCl for initial development of the tubers which confirmed that, fertilizers such as muriate of potash (MOP) and sulphate of potash (SOP) were more soluble than others such as polyhalite in all measurements [32]. Generally, K-release patterns did not necessarily follow DM decomposition patterns and argued that because K was released very rapidly, the balanced solubility and rapid decomposition of combined inputs complemented one another for yield advantages of treatment received 50 % PR combined with 50% KCl [40].

All yield and yield components recorded generally higher values at Abota-ulto site than at Gututo-ampokosha regardless of treatment for better adaptability for potato implied that both edaphic and climatic factors affect potato production (Table 5). This also confirms the findings of crops raised under sub-optimal conditions like as

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Gututo-ampokoysha will grow, but yields may be lower than crops grown under optimal conditions like Abota-ulto [41].

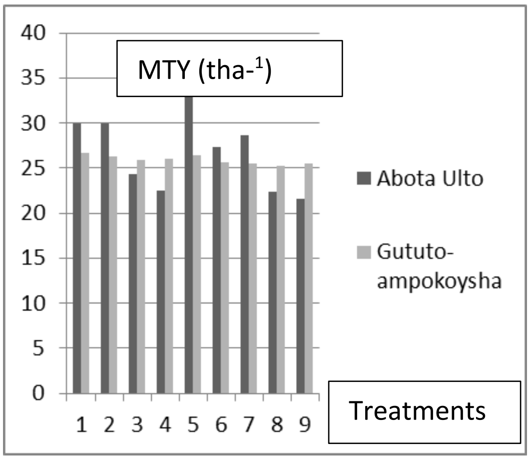

Figure 3: Graphical presentation of marketable TY

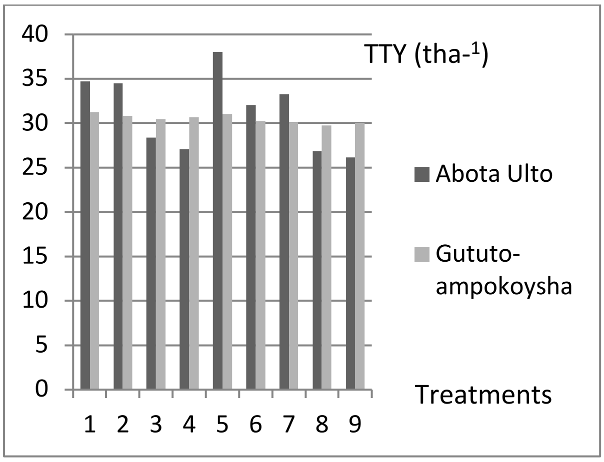

Figure 4: Graphical presentation of total TY

The result also related with the results from a study carried out on the effects of different fertilizers including K-fertilizer on potato in four locations of central Ethiopia revealed that MTY and TTY of potato were significantly and widely varied across sites [42].

The results of unmarketable tuber yield (UMTY) are categorized under two levels. That is the mean comparison with-in group localized as ‘a’ and ’b’. The treatment that received PR of 75 % equivalent to optimum KCl was grouped under ‘b’ grade while, the rest of treatments had got statistically no difference among treatments and grouped under ‘a’ grade value (Table 5). Treatments using a combination of 50 % CH with 50 % KCl and 50% CH with 50% PR showed lower results compared to other treatments. This may be due to the fact that coffee processing residues applied to the soil are generally observed to decompose more slowly [43]. This also confirms that at the time of tuber harvest, the researcher practically observed that partially decomposed unrecognizable black peat soil under coffee husk. This was explained due to the fact that the total amount of nutrients in plant residue is highly variable and differs depending on biological differences between individual crop species, above and below ground residues and crop yields [44]. For that some findings suggested that application of compost prepared or composted with bio-slurry, CH improved the fertility and pH of the soil [17]. This is due to addition of basic cations, ammonification and production of NH_3 during decomposition of the compost, adsorption of H^+ions, and increased microbial activity as a result of organic matter application and break down of organic matter for energy source and nutrient recycling (Table 2) [45].

Generally, as discussed above, most of the parameters performed differently at two different locations suggesting the necessity for proposing areas by amount and type of sources for its cultivation by considering both climatic and edaphic conditions [46]. Treatment with PR of 50 % combined with 50% KCl resulted in significantly higher yields and yield components, with the exception of specific gravity, across all sites. This was the case regardless of any differences in climate or soil conditions, ultimately leading to the highest achievable yields (Table 5).

Partial budget Analyses of K-fertilizer sources

The result of partial budget analyses data of two study sites are discussed separately.

At Abota-ulto site, the highest net benefits were obtained at treatment application of fixed standard combination of PR of 50 % KCl equivalent with 50 % of KCl per hectare. All treatments produced positive and acceptable marginal rates of return (greater than 100 % MRR) except for treatments that used a combination of PR of 50 % with 50 % of CH, and 50% of CH with 50 % of KCl. This suggests that the application of potato residue, especially when combined with KCl fertilizer, was economically feasible. However, treatments that involved a combination of 50 % of CH with 50 % of PR, as well as 50 % of KCl were not as cost-effective. The highest marginal rate of return (MRR) of 217.52 % was achieved with the standardized combined rates of 75 % of PR and 25 % KCl. This treatment was found to be the most economically viable, offering the highest net benefit of 899854.50 ETB. Another economically viable option was the combination of 50 % of PR with 50 % of KCl, which had an acceptable marginal rate of return of 107.4 %. For this study site, the standardized rates of PR applied in combinations were 1500 kg ha^{-1} (50 % of 3000 kg ha^{-1}) and 75 $kgha^{-1}$ of KCl (50 % of 150 kg ha^{-1}) for potato production on the selected sites (Table 6).

At the Gututo-ampokoysha site, the highest NB ha^{-1} (715434 ETB) was achieved also through the combined use of a fixed rate of 50 % of KCl per hectare. All treatments produced positive and acceptable marginal rates of return (greater than 100 % MRR) except for treatments that used PR of 100 %, combination of PR of 50% with CH of 50 % and combination of CH of 50 % with 50 % KCl. This also suggests that application of PR combination with KCl fertilizer was economically feasible. Treatments that involved a combination of CH of 50 % with PR of 50 %, as well as 50 % of KC and sole 100 % PR were dominated. At this site, the standardized rates of PR actually applied in combinations were PR of 1200 kg ha^1 (50 % of 2400 kg ha^1) and KCl of 60 kg ha^1 (50 % of 120 kg ha^1, was produced the highest MRR 168.38 % with the largest amount of NB ha^1 (715,434 ETB) (Table 6).

The results indicated that the use of selected treatment, 50 % of PR combined with 50 % of KCl, with varying actual amounts of mentioned sources for respective sites was profitable, economically viable and the most cost-effective rate of K-fertilizer source for production of potato at the aforementioned sites. It is important to consider that the sources of potassium can have an impact on both the tuber yield and quality. This should be taken into account when determining the final market goal for the produce Torabian *et al.* [34]. This also makes the poor small-scale farmers of the study areas very effective in utilizing the harvest obtained by selling to the market to meet other needs besides their capital need to run farming activities in the next period [31]. Treatments combined with CH were totally dominated at both sites, as shown in (Table 6).

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The research findings revealed inconsistencies in yield components such as plant height, tuber weight, and specific gravity among treatments, but they were found to be higher at Abot-ulto to Gututo-ampokoysha across the sites in almost all parameters. Consistently superior total tuber and marketable tuber yields were achieved with a treatment combination of 50 % potato residue (PR) and 50 % KCl of standards of 100 % KCl optimums across the sites, even though the actual amount of yield variations was lower at Gututo-ampokysha. This half-half combination of organic and inorganic potassium sources increased total tuber yield (TTY) by 33.5% and marketable tuber yield (MTY) by 30 % over the lowest, filling a wider amount of yield gap and representing that the organic and inorganic sources integrated in a balanced proportion to boost potato production more economically than either of one alone or proportionally unbalanced combinations.

The recommended combination is a mix of 50% PR (1500 kg PR ha^{-1}) with 50 % of 150 kg KCl (75 kg KCl ha^{-1}), totaling 1575 kg ha^{-1} for Abota-ulto site. According to Ehiosis (Ethiopian soil information system), this combination works for all potassium deficient wet-highland areas of Wolaita. For Gututo-ampkoysha site, the application is 50 % PR (1200 kg ha^{-1}) with 50 % of KCl (60 kg KCl ha^{-1}), totaling 1260 kg ha^{-1}, which could also be scaled-up to all potassium deficient mid-highland and low-land areas of Wolaita, with further verifications needed beyond that.

The selected treatment, a balanced combination of potato residue with KCl, has complementary effects on soil improvements in addition to potato productivity improvement. The fast solubility of KCl and the organic content and nutrient potential of potato residue can improve soil health conditions for sustainable agriculture. In the long run, the focus is on minimizing the proportions of inorganic KCl and maximizing potato residue based on these achieved results, with more proportional uses of potato residue and eventually shifting completely by increasing efficacy and awareness.

Data Availability

Data can be available upon the request from the authors.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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Table 1: Descriptions and compositions of treatments (residues and mixes of K- fertilizer sources)

Treatments (kgha^{-1})	Abota-ulto	Gututo-ampokoysha
1= 100% Optimum KCl (as a check)	150	120
2= 100% Equivalent PR	3000	2400
3 = 75% of equivalent PR	2250	1800
4= 125% of equivalent PR	3750	3000
5= 50% of (PR)+50% of KCl	1575	1280
6= 25% of (PR)+ 75% of KCl	862.5	690
7= 75% of (PR)+ 25% of KCl	2287	1830
8= 50% of (PR) +50% of CH	3125	2500
9= 50% of (CH)+ 50% of KCl	1700	1360

KCl= Potassium chloride, PR= potato residue, CH=coffee husk

Table 2: Contents of three major elements, lignin and phenols in 300 kg ha^{-1} K_2O from coffee residues

	Pulp	HuskCom	3ycomp	Buoy	1ycomp
DM applied residues (kg ha^{-1})	6402	10826	40816	7177	13992
FM applied residue (kg ha^{-1})	32010	11227	48019	7801	15045
K_2O (kg ha^{-1})	300	300	300	300	300
Total N (kg ha^{-1})	170	160	490	112	245
Total C (kg ha-1)	2734	4839	6122	3208	5597
Total phenols (kg ha^{-1})	150	157	180	107	213
Lignin (kg ha^{-1})	134	227	1278	149	427

DM = dry mass; FM = fresh mass; Pulp = coffee pulp; HuskCom = common coffee husk; 3ycomp = enriched and composted for 3 years coffee husk; Buoy = buoy coffee husk; 1ycomp = 1-year composted coffee husk

Source: Int J Recycl Org Waste Agriculture

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Table 3: Pre-planting selected physicochemical properties of the soil of the study locations

Locations	Texture class	DB (gcm^{-3})	pH	OC	TN	AvP (mgkg^{-1})	CEC	Ca^{2+}	Mg^{2+}	K^+	Na^+
				%			Cmol(+) kg^{-1}				
Abota-ulto	Clayloam	1.07	5.62	2.62	0.22	5.75	20.3	12.09	4.29	0.49	0.15
Gututo-amp	clayloam	1.09	5.08	2.42	0.24	2.13	18.8	12.37	3.20	0.51	0.16

Table 4: Main effects of K-fertilizer rates and locations on yield components of potato

Treatments (K-fertilizer Sources	PH (cm)	TNPP No	SPG (%)	Av. TW (gm)	DBMs (t ha^{-1})
Optimal KCl (check)	58bc	215.16bc	1.068e	71.35c	1.34a
Equivalent (100 %) PR	59.33abc	219.5ab	1.073cd	69.48d	1.14c
75 % of equivalent PR	58.83abc	222.5ab	1.0725d	72.46b	1.14c
125 % of PR	53.16d	211.83bc	1.08a	67.55e	1.27ab
50 % PR+ 50 % KCl	60.66ab	227a	1.076bc	73.69a	1.34a
25 % of PR + 75 % of KCl	56.33c	205.5c	1.073cd	72.25bc	1.28ab
75 % of PR + 25 % of KCl	61.16a	217.5ab	1.077ab	67.58e	1.25b
50 % of PR +50 % of CH	59.33abc	217.83ab	1.073cd	62.91f	1.32ab
50 % CH+ 50 % KCl	59.5ab	213.33bc	1.069e	63.65f	1.26b
Locations					
Abota -ulto	62.33a	226.44a	1.0738a	70.22a	1.401a
Gututo-amokoysha	54.63b	206.92b	1.0736b	67.76b	1.126b
LSD (0.05)	1.416	5.258	0.0016	0.448	0.0353
K-fertilizer Sources	***	***	***	***	***
Locations	**	**	ns	***	***
K-fertilizer Sources X Locations	***	**	**	***	**
CV%	4.37	4.38	0.27	1.17	5.05

PH= plant height, TNPP = Tuber number per plot, NUMTPP = Number of unmarketable tubes, Av.WT =Average tuber weight per tuber, Spr = Specific gravity, tha^{-1} = tons per hectare

*, ** = Statistically Significant, highly significant a t 0.05 and 0.01 probability levels respectively, ns = non-significant, Means within column(s) followed by the same letter(s) are not statistically different of each other as Duncan's Multiple Range Test at 0.05 probability level

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Table 5: Main effects of K fertilizer rates and locations on the tuber yield of potato (Gudane)

Treatments	MTY	UMTY	TTY
K-fertilizer Sources	**tha^{-1}**		
Optimal KCl (check)	27.05b	4.16a	31.2b
Equivalent (100 %) PR	26.9b	4.37a	31.3b
75 % of equivalent PR	24.19e	3.74b	27.93e
125 % of PR	22.43f	4.39a	26.82f
50 % PR+ 50 % KCl	30.99a	4.41a	35.4a
25 % of PR + 75 % of KCl	24.77d	4.39a	29.17d
75 % of PR + 25 % of KCl	25.51c	4.3a	29.89c
50 % of PR +50 % of CH	20.6h	4.18a	24.78h
50 % CH+ 50 % KCl	21.24g	4.19a	25.46g
Locations			
Abota Ulto	26.67a	4.55a	31.23a
Gututo-amokoysha	23.04b	3.94b	26.98b
LSD (0.05)	0.252	0.119	0.295
K-fertilizer Sources	**	***	***
Locations	***	***	***
K-fertilizer Sources X Locations	*	**	***
CV%	5.08	1.83	1.833

MTY = Marketable tuber yield, UMTY = Unmarketable tuber yield, TTY = Total tuber yield, tha^{-1} = tons per hectare

*, **= Statistically significant and highly significant a t 0.05 and 0.01 probability levels respectively. Means within column (s) followed by the same letter(s) are not statistically different of each other as Duncan's Multiple Range Test at 0.05 probability level

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Table 6: Partial budget analyses of K-fertilizer sources for locations

Site: Abota-ulto											
	TVC (ETBha^{-1})										
	K-source	*MTY	Adjusted MTY	GTB	Fertilizer	Residues					
K-fertilizer sources		kgha^{-1}		*ETB ha-1*	*KCl*	*CH*	*PR*	*Labor*	TVCtv	NB	MMR (%)
75 % of equivalent PR	2250	24330	21897	656910	0	0	900	225	1125	655,785	0
Equivalent (100 %) PR	3000	29940	26946	808380	0	0	1200	300	1500	806,880	402.92
50 % of PR +50 % of CH	3125	22360	20124	603720	0	812.5	600	296.25	1708.75	602,011.25	D
125 % of PR	3750	22540	20286	608580	0	0	1500	375	1875	606,705	28.33
75 % of PR + 25 % of KCl	2287	28610	25749	772470	1500	0	900	225	2625	769,845	217.52
50 % of PR +50 % of KCl	1575	33470	30123	903690	3000	0	600	235.5	3835.5	899,854.50	107.4
50 % CH+ 50 % KCl	1700	21576	19418.4	582552	3000	812.5	0	168.75	3981.25	578,570.75	D
25 % of PR + 75 % of KCl	862.5	27280	24552	736560	4500	0	300	108.75	4908.75	731,651.25	165.13
Optimal KCl (check)	150	29880	26892	806760	6000	0	0	45	6045	800,715	60.78
Site: Gututo-ampokoysha											
75 % of equivalent PR	1800	24050	21645	606060	0	0	720	180	900	605,160	0

Equivalent (100 %) PR	2400	23860	21474	601272	0	0	960	240	1200	600,072	D
50 % of PR +50 % of CH	2500	18840	16956	474768	0	650	480	237	1367	473,401	D
125 % of PR	3000	22310	20079	562212	0	0	1200	300	1500	560,712	656.47
75 % of PR + 25 % of KCl	1830	22400	20160	564480	1200	0	720	189	2109	562,371	3.38
50 % of PR +50 % of KCl	1280	28510	25659	718452	2400	0	480	138	3018	715,434	168.38
50 % CH+ 50 % KCl	1360	20910	18819	526932	2400	650	0	135	3185	523,747	D
25 % of PR + 75 % of KCl	690	22270	20043	561204	3600	0	240	87	3927	557,277	45.188
Optimal KCl (check)	120	24220	21798	610344	4800	0	0	36	4836	605,508	53.05

*MTY = Marketable tuber yield, GB = gross benefit, TVC = total variable cost, NB = net benefit, MRR = marginal rate of return, CH=coffee husk, PR=potato residue, KCl=potassium chloride **D = Dominated

Table 7: Yield of main crop products, mass of below ground (root) and above ground (stubble) residues and contents of nitrogen, phosphorus and potassium in their biomass

Crop	Yield t ha^{-1}	Root residues t ha^{-1}	Stubble t ha^{-1}	Total t ha^{-1}	N content kg ha^{-1}	P content kg ha^{-1}	K content kg ha^{-1}
Cereals							
Corn maize	5.85	1.12	2.26	3.38	39	3	19
Oats	3.78	1.52	2.38	3.90	55	8	58
spring barley	4.03	2.18	1.79	3.97	43	7	40
Winter wheat	4.93	2.84	2.76	5.60	53	9	42
Legumes							
Pea	3.18	1.58	1.30	2.88	112	14	74
Soybean	1.92	2.41	1.48	3.89	132	14	72
Root crops							
Potatoes	**19.50**	**1.57**	**0.87**	**2.44**	**59**	**6**	**61**
Sugar beet	49.95	0.61	0.50	1.11	20	2	13

Source: Residual plant nutrients in crop residues–an important resource,. Stanislav Torma *et al*. [17]

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