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Effect of Integrated Soil Amendment Practices on Growth and Seed Tuber Yield of Potato (Solanum tuberosum L.) at Jimma Arjo, Western Ethiopia

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Abstract
A field experiment was conducted to study the effect of integrated soil amendment practices on growth and seed tuber yield of potato at Jimma Arjo during the 2013 main cropping season. Totally, there were sixteen different treatments consisting of different organic and inorganic fertilizers. The experiment was laid out in a randomized complete block design with three replications. The results showed that integrated use of organic and inorganic fertilizer had significant effect on plant height, leaf area index, and total fresh biomass and stem number per hill. Tuber yield and its attributing characters like total tuber number per hill, average tuber weight, large tuber medium and small tuber size number and weight, marketable and unmarketable tuber number, marketable tuber yield, unmarketable tuber yield, total tuber yield and tuber dry matter were also significantly influenced. It was observed that integration of different organic and inorganic fertilizer had no significant effect on the days to maturity, harvest index and specific gravity. In general the application of wood ash, compost and farmyard manure alone or in combination in the absence of inorganic fertilizer did not prove much beneficial in promoting the growth, yield attributes and yield of potato. Application of 2 t/ha wood ash (WA) +5 t/ha farmyard manure (FYM) along with +111 kg N +92 kg P_2O_5/ha (RDF) resulted in the highest marketable tuber yield (12.74 t /ha) but was statistically in parity with RDF, however maximum total tuber yield was obtained with a combined application of 2 t/ha WA+5 t/ha compost (C) along with 100% RDF. The marketable and total tuber yield was positively and significantly correlated with growth components like plant height, total fresh biomass and stem number per hill. Similarly the marketable tuber yield was positively and significantly correlated with yield components like total tuber number per plant and marketable tuber number but negatively and significantly correlated with unmarketable tuber number.
Keywords: compost, farmyard manure, growth, soil amendment, wood ash, yield

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food crops in the world. In volume of crop, potato ranks fourth following wheat, maize and rice in the world (FAO, 2011). Potato is grown in 18.6 million hectares of land in 150 countries in the globe with an estimated annual production of 324 million tonnes (Singh, 2008). Among the root and tuber crops potato ranks top following by cassava, sweet potato and yams (Hawkes, 1990). As a result, potato cultivation is expanding rapidly in developing countries (Singh, 2008), almost doubling since 1991, with a corresponding increase in consumption (Hoffler and Ochieng, 2008; FAO, 2008). Potato is the rich source of starch, vitamin C and B and minerals. It contains about 20.6 % carbohydrates, 2.1% protein, 0.3 % fat, 1.1 % crude fibre and 0.9 % ash. It also contains a good amount of essential amino acids like *leucine*, *tryptophane* and *isolucine* (Kumar *et al*., 2012).

Ethiopia has good climatic and edaphic conditions for higher potato production and productivity (Endale *et al.,* 2008a). Compared to cereals, potato is short duration crop that can yield up to 30- 35 t/ha potato in 3-4 months in Ethiopia (Endale *et al.,* 2008b). In Ethiopia, average tuber yield of potato was almost constant between 6-8 t/ha in the last 20-30 years while the area planted with potato increased from 30,000 ha to about 160, 000ha in 2001 (Endale*, et al*., 2008a). The development and dissemination of many improved varieties of potato contributed to the improvement and expansion of potato production in Ethiopia. Most of the potato germplasm used for selection in Ethiopia are obtained from the CIP. The crop yield in Ethiopia is lower than that of most potato producing countries in Africa like Egypt and Zimbabwe, which produced 21 and 16t/ha, respectively (FAO, 2010).

The low hectarage and yield of potato in Ethiopia are attributed to many factors. The major ones are lack of well adapted and high-yielding cultivars, unavailability and high cost of seed tubers, inappropriate agronomic practices, and lack of marketing and suitable post-harvest management facilities as well as insect pests and disease (Berga *et al*., 1994; Tekalign, 2005; Endale *et al*., 2008a; Gildemacher *et al*., 2009a). In addition, drought, seed dormancy to fit the local cropping calendar, lack of improved characterization and *ex situ* conservation of existing potato genetic resources are very important limitations to the expansion of potato production by smallholder farmers in sub-Saharan-Africa (Fuglie, 2007).

Ayalew and Dejene (2011) stated that, declining soil fertility is one of the most significant constraints to increased food production in Ethiopia. Continuous cultivation of arable land without nutrient inputs results in degraded soils, accelerated soil erosion, depletion of soil nutrient reserves, reduced soil organic matter contents, loss of soil physical structure, and reduced crop productivity (Esilaba *et al.*, 2000). Soil nutrient depletion on smallholder farms has been cited as the biophysical root cause of the declining food production in Africa (Sanchez *et al.*, 1996). The soil fertility depletion problem could be overcome if the removal of nutrients resulting from harvests and other losses were being replaced.

The other major constraint to increased potato production is lack of good quality seed tuber. Access to improved seed tuber adapted to local conditions is the key to achieving sustained efforts towards food security. Agronomic practices of a seed potato crop are different from those of ware potatoes. Such practices in seed production are aimed at a high rate of multiplication, high yield of seed –sized tubers and maintenance of healthy seed tubers that have optimum physiological quality (Lung'aho *et al.,* 2007).

Since potato is propagated vegetative mostly using seed tuber, the quantity of planting material (tubers) required to plant a unit area of land is large. This results in depth and bulkiness of tubers seeds and difficulty in handling them. Therefore, optimum sized tubers should be produced to use for seed. Medium-sized tubers of 35 - 45 mm diameter or 40-75 g are preferred planting. One hectare can be sufficiently planted with 2.0 to 2.5 tons or 44, 444 tubers are this spacing (Lung'aho *et al*., 2007).

Farmers in the areas apply organic fertilizers particularly animal manure and also chemical fertilizers. But the manure is restricted only to homestead areas due to shortage of the material to cover the outfield, and the chemical fertilizers are applied far below the recommendation due to the high price of fertilizers.

The excessive use of mineral fertilizers only has caused adverse effect on soil nutrient balances and, thus reduced plant growth performance .This further justifies the need to use organic fertilizers. Animal manure is commonly used on higher value commodities such as potato, coffee and vegetables (Freeman and Coe, 2002; Shapiro and Sanders, 2002). As with manure, farmers have shifted promising innovations using new green organic systems or integration of organic and mineral fertilizer on to high commodities such as potato and vegetables (Place *et al*., 2002). The integrated nutrient management paradigm acknowledges the need for both organic and inorganic mineral inputs to sustain soil health and crop production due to positive interaction and complementarities between them (Sanchez and Jama, 2000; Vanlauwe *et al*., 2002a). It is a strategy that incorporates both organic and inorganic plant nutrients to attain higher crop productivity, prevent soil degradation and thereby help meet future food supply needs. It has been acknowledged that organic and inorganic mineral inputs cannot be substituted entirely by one another and are both required for sustainable crop production (Place *et al*., 2003). This is due to practical reasons as fertilizer or organic resources alone may not provide sufficient amounts or may be unsuitable for alleviating specific constraints to crop production (Sanchez and Jama, 2000). Thus the present study was conducted with the following objective.

- To study the effects of integrated nutrient management practices on seed tuber yield and yield components of potato.

2. LITERATURE REVIEW

2.1. The Potato Plant

The Irish potato (*Solanum tuberosum* L.) is the most important non-cereal crop in the World (Struik and Wiersema, 1999). It is originated in the highlands of South America and is cultivated in 157 countries in the tropical, subtropical and temperate zones of the world (FAO, 2010). Even though eight species are cultivated the most common is *S. tuberosum*, a tetraploid (2n=4x=48) which produces tubers under long-day conditions and is cultivated worldwide. The other seven species are found mainly in the Andes and produce tubers under short-day conditions. These include the tetraploid subspecies *S. tuberosum andigena*, the diploid (2n=2x=24) species, *S. ajanhuiri*, *S. goniocalyx*, *S. phureja S. stenotomum*, the triploid (2n=3x=36) species *S. chaucha*, and *S. juzepczukii*, and the pentaploid (2n=5x=60) *S. curtilobum*. Approximately 187 wild *Solanum* species, which are closely related to the potato, are distributed from the United States of America (USA) to the south of South America (FAO, 2010).

The potato is an herbaceous annual that grows up to 100 cm tall and produces a tuber – also called potato – so rich in starch. The potato belongs to the Solanaceae – or "nightshade"– family of flowering plants, and shares the genus *Solanum* with at least 1000 other species, including tomato and eggplant. Recent research indicates that *S. tuberosum* is divided into two, only slightly different, cultivar groups: *Andigenum,* which is adapted to short day conditions and is mainly grown in the Andes, and *Chilotanum,* the potato now cultivated around the world (FAO, 2009).

Potato is traditionally grown from tubers, but it also can be grown from other vegetative organs such as stems or sprouts, and also from true seed (FAO, 2010). As the potato plant grows, its compound leaves manufacture starch that is transferred to the ends of its underground stems (or stolons). The stems thicken to form a few or as many as 20 tubers close to the soil surface. The number of tubers that actually reach maturity depends on available moisture and soil nutrients. Tubers may vary in shape and size, and normally weigh up to 300 g each. The tuber is an underground modified swollen stem that serves as a storage and reproductive organ

(FAO, 2009).

2.2. Importance of Potato

Increasing population has resulted in reduction of arable land, and this coupled with climate change and instability together with frequent occurrences of natural disasters, have made food security as a crucial issue in the world. Hence, increased food supply and availability has become a priority in the world's development agenda. Potato is a preferred crop in achieving this goal especially in developing countries due to its high nutritional value, adaptability to diverse environments and high yield potential per unit area and time. Out of the four major food crops (rice, wheat, potato and maize), potato has the best potential for yield increases (Fengyi, 2008).

The potato is already an integral part of the global food system. It is the world's number one non-grain food commodity, with production reaching a record 325 million tonnes in 2007. Potato consumption is expanding strongly in developing countries, which now account for more than half of the global harvest and where the potato's ease of cultivation and high energy content have made it a valuable cash crop for millions of farmers. At the same time, the potato – unlike major cereals – is not a globally traded commodity. Only a fraction of total production enters foreign trade, and potato prices are determined usually by local production costs, not by the vagaries of international markets. It is, therefore, a highly recommended food security crop that can help low-income farmers and vulnerable consumers ride out extreme events in world food supply and demand (FAO, 2009).

The potato produces more nutritious food more quickly, on less land, and in harsher climates than any other major crop – up to 85 percent of the plant is edible human food, compared to around 50 percent in cereals. Potato is rich in carbohydrates, making it a good source of energy. It has the highest protein content (around 2.1 percent on a fresh weight basis) in the family of root and tuber crops, and protein of a fairly high quality, with an amino-acid pattern that is well matched to human requirements. Potato is also very rich in vitamin C – a single, medium-sized potato contains about half the recommended daily intake and contain a fifth of the recommended daily value of potassium (FAO, 2009). The potato is the world's most important tuber vegetable with a vital but often underappreciated role in the global food system. It is a staple food that supplies the energy and nutritional needs of more than a billion people worldwide. Potato cultivation and post-harvest activities constitute an important source of employment and income in rural areas and for women in developing countries. It can be used as a food security crop, as a cash crop, as animal feed, and as a source of starch for many industrial uses. In honor of its versatility, nutrition and emerging status in the developing world, the United Nations named 2008 the International Year of the Potato (FAO, 2009). The International Year of the Potato (IYP) in 2008 was a celebration of one of humanity's most important and universally loved staple foods.

The potato crop is ideally suited for places where land is limited and labour is abundant, conditions that characterize much of the developing countries. Moreover, the potato is a highly productive crop. It produces more food per unit area and per unit time than wheat, rice and maize. Potato's short growth cycle also adds its value to securing food availability at household level by improving farm productivity through permitting double crop production per annum. As Kabira *et al.* (2006) also indicated that, potato plays an important role in national food and nutrition security, poverty alleviation, and income generation and provides employment in production to consumption continuum.

2.3. Ecological Requirements of Potato

Potato is a cool-season crop that grows well in higher altitudes. It prefers cool weather and temperature between 16-25 ^{0}C that favours foliage growths, net photosynthesis, and tuberization (Levy, 1992). Although potato is a remarkably adaptable crop to different agro ecologies, its expansion has been restricted by high temperatures in some regions of the world (Levy, 1986). Rate of sprout development from seed pieces depends on soil temperature. Very little sprout elongation occurs at 6°C. Elongation is slow at 9°C and is maximized at about 18°C. The optimum soil temperature for initiating tubers is 16-19°C. Tuber development declines as soil temperatures rises above 20°C and tuber growth practically stops at soil temperatures above 30°C. The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favour development of large tubers (Western Potato Council, 2003).

The higher elevations above 1500 meters above sea level are cooler and therefore congenial for seed tuber production due to low aphid population (Kadian *et al*., 2010). Yields are highest when average daytime temperatures are about 21°C. Cool night temperatures are important because they affect the accumulation of carbohydrates and dry matter in the tubers. At lower night temperatures, respiration is slowed, which enhances storage of starch in the tubers (Western Potato Council, 2003). High temperature inhibits tuberization in both short and long photoperiods, although its effect is much greater under long photoperiods. High temperature affects the partitioning of assimilates by decreasing the amount going to the tubers and increasing the amounts to other parts of the plant; similar effects are also observed in long photoperiods. Exposing the shoot to high temperatures (30-35^{o}c) had the greatest inhibitory effect on induction to tuberize as determined by tuberization of cuttings taken from the plants after the treatment (Ewing and Struik, 1992).

The root system on the potato plant is not extensive and ample soil water is necessary whether from rain or supplemental irrigation. Potatoes require a continuous supply of soil water along with adequate soil aeration. Yields are greatest when soil moisture is maintained above 65% of the available soil water (ASW) capacity. Tuber set is particularly sensitive to moisture stress. There are generally fewer tubers set when available soil moisture is maintained below 65% of the ASW capacity. The amount of water needed by potatoes varies with the soil type, temperature, humidity, air movement, plant and stem populations, variety and cultural practices (Western Potato Council, 2003).

Potato plants require a well drained soil so that the roots have adequate oxygen. Unless irrigation facilities are available, the soil should not be too droughty. The most attractive tuber shape and skin appearance are achieved with light, sandy soils or with muck soils. The ideal pH for good potato growth is between 4.8 and 5.4. Potatoes grow well at a higher soil pH, but scab can be a problem. If it is not practical to maintain a low pH, scab resistant cultivars must be grown. The rate of nitrogen fertilization is a key consideration in managing fertility, because excessive applications delay maturity and reduce the partitioning of dry matter to the tubers, not to mention possible adverse effects on processing quality and on the environment (Ewing, 1997). Low levels of irradiance have effects similar to long photoperiods and high temperatures on the morphology of the potato plant, and the effects are exacerbated when these factors are present in combination. In addition, low light intensity increases stem elongation and delays plant senescence (Demagante and Van Der Zaag, 1988).

According to Lung'aho *et al.* (2007) the growth and quality of potatoes is influenced by several factors including temperature, moisture, light, soil type, nutrients, variety, size of seed tubers, plant stand, stem population, pest management, planting date and harvest date. It is only when all factors that influence growth of the crop are at optimum levels can the most profitable yields of quality seed potatoes be attained(Lung'aho *et al.*, 2007).

Among African countries, Ethiopia has possibly the greatest potential for potato production: 70 percent of its arable land – mainly in highland areas of above 1500 m –is believed to be suitable for potato production. Since the highlands are also home to almost 90 percent of Ethiopia's population, the potato could play a key role in ensuring national food security. At present, potatoes are still widely regarded as a secondary crop, and annual per capita consumption is estimated at just 5 kg. However, potato growing is expanding steadily: FAO estimates that production has increased from 280 000 tonnes in 1993 to around 525 000 tonnes in 2007 (FAO, 2009).

Ethiopia is divided in to 18 major agro-ecologies. Most of these agro-ecologies have suitable climatic and edaphic conditions for the production of high yield of quality potatoes. High yields are obtained in the central, southern, south-eastern, south-western and north-western parts of the country (Gebremedhin *et al*., 2008a). Most of the lands which are potentially suitable to potato cultivation are found in the Central Highlands, at an altitude range of 1,500 - 3,000 meters above sea level with annual precipitation of 600 - 1,200 mm (Gebremedhin *et al.,* 2001). The highlands of Ethiopia (defined as land above 1,500 meters above sea level) where the potato is generally well suited, cover 44 percent of the nation's area, in which 88 percent of its population dwells and 95 percent of its cropped area belongs (Grepperud,1996). As Adane *et al.* (2010) indicated, in Ethiopia, potato is grown in four major areas: the central, the eastern, the north-western and the southern. Together, they cover approximately 83% of the potato farmers.

2.4. Soil Fertility Management

Soil organic and inorganic fertilizers are important for agricultural sustainability because of their possible beneficial effects on soil properties and long-term soil productivity. Several studies have been conducted to assess the effects of soil organic and inorganic fertilizers on soil properties and crop yields, and different agronomic and environmental outcomes have been observed depending on the specific agro ecosystem (Saha *et al*., 2008).

Some of the primary effects of use of organic fertilizers are increased soil organic matter (SOM) and improved soil properties for crop growth (Hati *et al.*, 2006; Saha *et al.*, 2008). Among the benefits of maintaining or increasing SOM are increased soil water-holding capacity, improved soil structure for root growth and drainage, accelerated rates of nutrient cycling (Garcia-Gil *et al*., 2000) and higher content of soil nutrients over a longer period of time, increased CEC, and greater soil biological activity (Woomer *et al*., 1994). These changes in soil properties improve soil quality and the long-term sustainability of agro ecosystems (Gupta *et al*., 1994). Because of its high water holding capacity, SOM has particular importance in sandy soils since it improves soil water availability for plants and water storage (Tester, 1990; Rawls *et al.*, 2003).

Cultivation of soil, especially through tillage, affects soil physical properties by altering soil structure and promoting loss of SOM. However, these potentially negative impacts of tillage can be minimized by adding large amounts of crop residues (Karlen *et al.,* 1994) or organic fertilizers, such as farm manure (Mando *et al.,* 2005).

Inorganic fertilizers are an important management input to achieve good crop yields especially in systems where soil resources are nutrient deficient and the main goal is to increase crop productivity (Haynes *et al*., 1998). However, use of chemical fertilizers alone may not be sufficient under intensive agricultural management. Over-reliance on use of chemical fertilizers has been associated with declines in some soil properties and crop yields over time (Hepperly *et al*., 2009) and significant land problems, such as soil degradation due to over exploitation of land and soil pollution caused by high application rates of fertilizers and pesticide application (Singh, 2000). Residual effects of applied organic and inorganic soil fertilizers on soil properties vary based on different factors, including type, rate and timing of application and soil characteristics. Extensive research has reported improved soil properties including a higher content of residual soil nutrients over a longer period of time due to organic soil amendments. For example, manure and vermicompost significantly increased soil organic carbon (SOC) and decreased bulk density over time (Saha *et al.,* 2008) and the residual effect of total SOC and soil P lasted up to seven to eight years when manure was applied in a semi-arid dry land agriculture (Kihanda *et al.,* 2006). Inorganic fertilizer application modestly increased SOC (Yadav *et al.,* 1998; Kihanda *et al.,* 2006; Saha *et al.,* 2008) which was mainly attributed to increased biomass production that resulted in increased soil organic C input from root and crop residues.

Inorganic and organic fertilizers applied together are of importance to agricultural sustainability mostly for their significant effect on soil productivity as well as on soil properties. Numerous studies reported that combinations of soil organic with soil inorganic fertilizers are more beneficial for soil properties and crop production than either fertilizer applied alone. For instance, in a cassava-based cropping system with application of organic and inorganic fertilizers, soil available P was increased and SOC was relatively stable (Ayoola, 2006). Other studies reported that SOC and soil total N was increased with organic and inorganic soil amendments (Goyal *et al.,* 1999). A combination of manure and chemical fertilizer resulted in consistent availability of NO3 - during the growing season (Nyiraneza and Snapp, 2007). In plots that received a combination of inorganic and organic fertilizers for the last 11 years, the SOM concentration and soil microbial activities, which are important for the nutrient turnover and long-term productivity of the soil, were significantly increased compared to plots that received inorganic fertilizer only (Goyal *et al*., 1999). Due to their residual value that could last for several years of cropping, organic amendments can be intermittently applied to soils and supplemented by chemical fertilizers to rapidly supply immediate nutrients required by crop plants (Kihanda *et al*., 2006)

2.4.1. Response to inorganic fertilizer

Inorganic fertilizers are very important in the cultivation of horticultural crops and are increasingly used. This increase is due to shortage of animal manures and residues and to the increasing knowledge of their value (Mathew and Karikari, 1990). Inorganic fertilizers will remain a key component of soil fertility management and an essential element of any agricultural development strategy or plan to increase food production. Various reports showed that use of inorganic fertilizers in the tropics had stagnated, and this was explained by poor marketing and inadequate profitability from inorganic fertilizer use (William, 1999). According to Muriithi and Irungu(2004) application of inorganic fertilizer in the form of DAP at the rates of 90kg N/ha +230kg P_2O_5 significantly increased the vigor of the potato plants compared to the other treatments. The results also indicated that there were significant responses to application of inorganic fertilizer to the potato crop when compared to the use of FYM alone.

Soil application of nitrogen and phosphorus is a basic necessity for crop growth and yield. As do most other field crops, potato responds well to improved management practices, among which N and P fertilization plays an important role in producing satisfactory yields (Beukema and van Der Zaag, 1990). Only 15-20% of applied phosphate fertilizer to a crop is utilized, the rest of 80% remains unutilized in fixed forms and other reaction products. Fertilizer experiments in most potato growing areas indicated N nutrient requirement of potato to be very high. Nitrogen fertilizer is generally needed because of its mobility in soils and the large amounts needed by the plant (Westernmann and Kleinkopf, 1985). Potato yield, however, can be adversely affected by both insufficient and excess soil N. High soil N delays tuber initiation and promotes excessive vegetative growth at the expense of tubers. Thus, addition of N above the recommended rate did not increase yield and even reduced it for late maturing varieties mainly because of delayed tuber enlargement period. Similarly, excess phosphorus may disturb the nutrient balance within the plant and decrease both potato yield and quality.

2.4.2. Response to organic fertilizer

The use of organic manure as a fertilizer in less developed countries like Ethiopia has received much attention from economic point of view. In view of the current worldwide shortage of chemical fertilizers and its anticipated adverse effect on food production, the endeavor to discover and develop efficient techniques of utilizing organic materials as fertilizer is urgently needed. Organic fertilizers were regarded as important, but it was realized that organic fertilizers would not be available in sufficient amounts to increase food production drastically (Place *et al*., 2003). According to Shalini *et al*. (2002), application of organic manures increased uptake of N, P and k over application of inorganic fertilizers alone. The result of several long term experiments in different cropping systems also revealed that, long- term sustainability of productivity in intensive cropping systems also revealed that, long –term sustainability of productivity in intensive cropping system could be achieved only through integration of inorganic and organic source of nutrients.

Similarly, Shivanand (2002)reported that application of organic materials like FYM, compost or green manure in combination with inorganic fertilizer improved soil physical properties and cat ion exchange capacity, exchangeable calcium, available nutrient N, P, K and Zn , Mn, Cu and Fe were increased significantly with organic materials in conjunction with inorganic materials. The author finally concluded that the uptake of nitrogen, phosphorus, potassium and Zinc, manganese, copper, iron increased significantly by crops when 50 percent of organic in combination with 50 percent inorganic fertilizers are applied. Balesh (2005) also confirmed that organic fertilizers constitute important sources of nutrients and decomposable organic matter for increasing yield and improving soil fertility. The importance of organic manure is also being realized again because of prohibitive costs of inorganic fertilizers and poor purchasing power of marginal and small farmers (Tolessa *et al*., 2001).

2.4.2.1. Response to farmyard manure

Farmyard manure (FYM) is among the important soil amendments to which farmers have access in mixed farming systems. In addition to its nutrient supply, farmyard manure improves the physicochemical conditions of soils. The wide spread use of farmyard manure greatly depends, among others, on proper application methods, which increase the value, reduce costs, and enhance effectiveness (Teklu *et al*., 2004). Of all field crops, the potato has the best response to farmyard manure (Beukema and van Der Zaag, 1990). Although the macro and microelements applied to the potato field contribute to soil fertility, the soil improving effect of organic matter is often considered to be of major importance. Beukema and Van der zaag (1990) further suggested that depending on the animal ,the feeding,10 tones of FYM could contain: 15 kg of N, 6kg of P_2O_5, 40kg of K_2O, 50kg of Cao, 17kg of Mg, 300g of Mn, 40 g of Cu and 50 g of Bo. Sikka (1982) also reported that application of FYM may contribute to an improvement in the efficiency of the phosphate application. According to Beukema and van Der Zaag (1990) the crop benefits from the application of FYM not only from the amounts of nitrogen, phosphorus and potassium it contains but also from its improving effects on the tilth and the moisture retaining properties of the soil.

Increased yields of cereal and other crops due to application of FYM have been reported by Hegde (1998). Tolessa (1999) also reported that application of FYM in maize significantly increased nitrogen, phosphorus and potassium status of the soil as compared to inorganic fertilizers application. The author also revealed that there was significantly increase in total nitrogen, available phosphorus and potassium content of the soil with increases in FYM levels from 8 to 24t/ha. Similarly, Jayaprakash (2001) reported that significantly higher grain yield of maize was recorded due to application of organics; compost and FYM at the rate of 2t/ha and 10t/ha. The author also asserted that the higher grain yield of maize due to application of FYM and compost was attributed to significantly high growth and yield components.

2.4.2.2. Response to compost

The use of compost can overcome the problem of shortage of farmyard manure as compost can be made from locally available materials such as grass, clippings, leaves, weeds, vegetable peels, animal manure etc. For small holder farmers, compost is important source of nutrients and necessary to manage soil fertility (Giller, 2006). A research conducted in Taiwan indicated that application of compost increased the availability of N and P (Chen *et al*., 2001). In addition to providing an essential nutrient, compost also improves soil structure and benefit soil organisms (Pretty, 1995). However, since compost contains less nutrient concentration as compared to chemical fertilizers and it releases nutrients slowly, unless applied in very large amounts it doesn't provide all the NPK nutrients which are highly required by crops (Emiru, 2004).

The utilization of compost as an organic manure has been reported by several authors (Kachapur *et al*., 2001; Shanward *et al*., 2001). According to Kachapur *et al*. (2001) compost use in crop production is gaining importance due to yield benefits and also it improves the soil physical and chemical properties.

Another study made by Shanward *et al*. (2001) in sun flower showed that among the organic manures application of compost recorded higher seed yield than poultry manure and FYM. Compost decomposes readily and thus releases nutrients at faster rate than FYM (Shalini *et al*., 2002). However, results obtained were on increased growth attributes like plant height, number of leaves and dry matter produced per plant. The authors finally concluded that this is further substantiated by higher up take of major nutrients like nitrogen, phosphorus and potassium. Similarly, Kang (2004) reported that application of compost was more favorable than the effect of application of a chemical fertilizer on growth and yield characteristics of fall cropping of potato. The author further concluded that application of 8-10t/ha of compost resulted in an increase in the total tuber yield.

2.4.2.3. Response to wood ash

Wood ash has traditionally been used as fertilizer. Some studies have shown that bottom ashes may be used as fertilizer in agriculture and forestry (Fritze *et al.,* 2000). Demeyer *et al*. (2001) found a positive effect of ashes on soil texture, aeration, water holding capacity and cation exchange capacity. The general notion is that fertilization with ashes has short term effects lasting for approximately one year (Fritze *et al*., 2000; Zimmerman and Frey, 2002). Phosphate solubility in ashes is low (Vesterinen, 2003) and according to Moilanen *et al*. (2006) application of ash promotes plant growth only if there is no N limitation. If ashes are considered to be used as fertilizers, their heavy metal content needs to be limited.

According to several authors (Demeyer *et al*., 2001; Fritze *et al*., 2000; Perkiomaki and Fritze, 2002; Zimmermann and Frey, 2002) ash amendment increases soil microbial activity and biomass. In contrast, however, ash amendment to soils has also been found to inhibit fungal growth (Baath *et al*., 1995). Perucci *et al*. (2006) studied the effect of addition of wood ash at 5 and 20 t /ha on soil microbial and biochemical properties. The soil microbiological biomass (C and N), and general microbial activity increased at the lower wood-ash dose, whereas microbial biomass C decreased at the higher ash dose. A changed microbial C/N ratio of treated samples suggested changes in the structure of the microbial communities.

2.4. 3. Integrated nutrient management (INM)

Integrated nutrient management (INM) is an approach that involves the management of both organic and inorganic plant nutrients for optimal production of cultivated crops, forage, and tree species, while conserving the natural resource base essential for long-term sustainability (Smaling, 1993). Moreover, According to Woomer *et al*.(1999) an approach to improving INM separates management practices in to four general categories; nutrient recycling, livestock-crop interaction, biological nutrient fixation and fertilizer use. INM seeks to maximize the complementarily of mineral and organic nutrient sources (Janssen, 1993). For sustainable crop production integrated use of inorganic and organic fertilizers has proved to be highly beneficial (Anderson *et al*., 2002). Similarly, Mollah *et al*. (2011) stated that sustainable crop production could be possible through the integrated use of organic manure and chemical fertilizers. Moreover, INM reduces erosion, improves water infiltration, soil aeration and plant root growth and also it minimizes the risk of downstream flooding (Smaling, 1993). Prativa and Bhattarai (2011) reported that, the integration of organic manures in combination with inorganic fertilizers was found significant in improving the overall plant growth, yield and soil macro-nutrient status than the sole application of either of these nutrients.

2.4.3.1. Integrated use of compost and inorganic fertilizer

The research reported by Kachapur *et al*. (2001) indicated favorable effect of compost and inorganic fertilizers on the production of Kahrif sorghum. It was concluded that crop had to be supplied with inorganic and compost for higher and sustainable yield. Application of compost along with inorganic fertilizer produced significantly higher yield than application of in organic fertilizer alone (Shalini *et al.,* 2002).

2.4.3.2. Integrated use of farm yard manure and inorganic fertilizer

Various researchers reported that supplementing the inorganic fertilizers with farmyard manure substantially increased both quantity and quality of potato (Tolessa, 1999; Teklu *et al*., 2004.). The decision whether to apply the full dose of recommended rate of the N and P or the reduced rates depends on various socio economics factor such as the efficiency, profitability, affordability and availability, of the fertilizers. The experiment conducted at Kenya showed that well decomposed farmyard manure can be used in combination with inorganic fertilizers to improve soil fertilizers to improve soil fertility and potato tuber yield in smallholder farms (Muriithi and Irungu, 2004). The same authors also reported that considering cost of inorganic fertilizer and its negative effects on the environment, reduced usage at half the recommended rates combined with half rates of farmyard manure is feasible option friendly to the farmer's soil and environment. Shanward *et al. (*2001) revealed that combination of N and P fertilizer each at 50 kg/ha with farmyard manure at 5 t/ha increased yields significantly. Similarly manure at half rates and farmers practice also resulted in more vigorous plant growth compared to applying farmyard manure alone.

Complementary use of chemical fertilizer and organic manures has assumed great importance nowadays to maintain as well as sustain a higher level of soil fertility and crop productivity (Shalini *et al.,* 2002). Combined application of organic and inorganic help to improve the physico-chemical properties as well as biological properties of soils .potatoes are plants with along vegetation period' therefore they assimilate nutrients from organic and mineral fertilizers rather intensively (Makaraviciute, 2003). According to Shalini *et al.* (2002) application of organic manure with inorganic fertilizer significantly increased growth and vigor of the plants over application of inorganic fertilizers alone.

Tolanur (2002) also reported that cation exchange capacity; exchangeable calcium available nutrients N, P, K and Zn were increased significantly with organic materials in conjunction with inorganic materials. Similarly, Ring- Xaing *et al.* (2001) reported that reasonable application of inorganic and organic fertilizer decreased soil bulk density, increased soil moisture, soil fertility, growth of maize and promoted maize and promoted maize grain quality. Romero-Limma *et al*. (2000) also found that the combination of mineral and organic fertilizers improves the quality of potatoes and that heavy mineral fertilization reduced the biological value of proteins in tubers. It is suggested that the reasonable application ratio of combined inorganic and organic fertilizer ranging raging from 25 to 50 percent chemical fertilizers should be applied for maize fodder production. To reduce the use of agrochemicals, among them the fertilizers and increase the yield and quality of the product, an alternative is the use of organic fertilizer in low doses, complemented with mineral fertilizer to meet the nutrient requirements of the crop. The result of a large numbers of experiments on manure and fertilizers conducted in several countries revealed that neither chemical fertilizer alone. Nor organic sources used exclusively can sustain the productivity of the soils under highly intensive cropping system (Singh and Yadav, 1992).

2.4.3.3. Experience of other countries on integrated nutrient management

Many studies in different African countries have found that poor farmer's inability to access mineral fertilizers has adverse consequence on soil fertility. Kenya farmers, For example often incorporate more than one nutrient source on their farms (Place *et al.,* 2003). Freeman and Coe (2002) also found that 37 percent of farmers in the relatively drier zones of Kenya used both organic and mineral fertilizers. In the western Kenyan highlands more than two- thirds of farmers using mineral fertilizers also used animal manure (Place *et al*., 2002a). There are also selected cases of organic/mineral fertilizer system such as in Malawi, where farmers use both organic and inorganic fertilizer. There are also cases of high adaption rates of 0rganic and inorganic in areas of Nigeria (Adesina and Chianu, 2002) and Cameroon (Houdenkon, 2000). However, the relative adoption rates between organic and mineral fertilizers vary by location. The most striking case may be Rwanda where only 2 percent of the plots received mineral fertilizers (Place *et al*., 2003).

3. MATERIALS AND METHODS

3.1. Description of Study Area

The study was conducted at Jimma Arjo sub-site of Bako Agricultural Research Center, during 2013 main cropping season. The area is situated in the western part of Ethiopia at a distance of 379 km away from Addis Ababa. It lies at latitude of $8^{0}73^{'}$ North-South and longitude of $36^{0}51$'East-West and at an altitude of 2520 m above sea level. It has tropical and sub-tropical types of climate. The mean annual temperature ranges between 15^{0}C and 20^{0}C whereas the mean annual rainfall is between 1400 and 2000mm. The rainy season extends from May to October and maximum rain is received in the months of June to August. The area is known for the mixed crop-livestock Farming system in which cultivation of potato, sweet potato, teff*,* wheat, barley, faba beans, peas, sorghum, maize and millet are known **(**Jimma Arjo information Center).

3.2. Experimental Materials

Farm yard manure was collected from the locally available cow dung from the farmer's field. Fresh cows manure was piled and stored for three months before application after decomposition (Arakeri *et al*., 1962).

The compost was prepared under a shade of tree. The heap of the compost has a height of 1.6m and abases area of about $4m^2$.The principal ingredients of the compost were coarse plant materials (twigs and small branches), local grasses, banana leaves and other weeds, fresh cow dung and urine. The source of wood ash was from farmers' house near to the site.

Nitrogen was applied through UREA and DAP while phosphorus was supplied through DAP .Potato variety Gudene released nationally by Holetta agricultural research center was used as a planting material

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3.3. Treatments

The treatments used in the experiment are given below

1. Control
2. 10.0t//ha compost
3. 10.0t/ha farmyard manure
4. 4.0t/ha wood ash
5. Recommended rate of N and P fertilizer (111kgN +92kgP_2O_5/ha)
6. 5.0 t/ha compost +50% recommended NP
7. 5.0t/ha fym+50% recommended NP
8. 2.0t/ha wood ash+50% recommended NP
9. 2.0t/ha wood ash+5.0t/ha compost
10. 2.0t/ha wood ash+5.0t/ha farmyard manure
11. 2.0t/ha wood ash+5.0t/ha compost +50% recommended NP
12. 2.0t/ha wood ash+5.0t/ha farmyard manure+50% recommended NP
13. 2.0t/ha wood ash+5.0t/ha compost +100 % recommended NP
14. 2.0t/ha wood ash+5.0t/ha farmyard manure+100% recommended NP
15. 2.0t/ha wood ash+ 100% recommended NP
16. 2.0t/ha wood ash+5.0t/ha compost+5.0t/ha farmyard manure +100% recommended NP

3.4. Experimental Design

The experiment was laid out in a randomized complete block design with three replications. The plot size was 3.6 x3.0 m. The inter-and intra-row spacing was 60 and 25 cm, respectively. Thus there were six rows and 12 plants within each row. The distance between the plots and blocks was maintained at1m and 2m, respectively. The outer most one row on both sides and two plants on both ends of each row were the border plants. Thus net plot size was 2.4m x2.0m

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3.5. Crop Management

The field was prepared by a tractor. Each plot was manually leveled. As per the treatments plan the organic manures *viz*., Well rotten farmyard manure, compost, wood ash were applied to the respective plots. The half of nitrogen (N) and full dose of phosphorous were applied in the form of urea and DAP respectively during the planting to the respective plots. The remaining N was applied at flowering stage. Well-sprouted medium sized potato tubers were planted on 21 May during 2013 main cropping season. Hand weeding was done when required, to keep the plots clean and free from weed competition. Totally three weeding were done during the period of experimentation. One week before harvesting the haulm was cut and the crop was harvested by digging when the soil moisture was optimum.

3.6. Soil Sampling and Analysis

Soil sampling and analyses was done before sowing the crop. Before sowing, the soil samples from the entire experimental fields of the study sites were taken randomly in a W-shaped pattern from the whole experimental plots. Ten samples were taken using an auger from each arm of the W shaped lines of the field to a depth of 0-30cm and thoroughly mixed. From this mixture, sample weighting 1kg was taken and replicated 3 times for analysis. Before analysis, the sample soil was air-dried, sieved through a 2mm sieve mesh. The composite soil sample was analyzed for selected physicochemical properties mainly textural analysis (sand, silt and clay), soil pH, total nitrogen (N), organic matter content, available phosphorus (P), cation exchangeable (CEE) capacity, and exchangeable potassium using the appropriate laboratory procedures. Organic matter was determined by the Balkey and Blank procedure (Walkey and Blanck, 1934) while total nitrogen was determined using the Kjeldhal method (Dewis and Freites 1970). The pH of the soil was measured in water at soil to water ratio of 1:2:5 potentiometric –PH mater with glass electrode, and cation exchange capacity measured by ammonium acetate method after saturating the soil with 1 N H4OAC (Chapman, 1965). Available phosphorus was determined by the Olsen method (Olsen *et al.,* 1965). Soil texture analysis was performed by Bouyoucous hydrometer method (Day, 1965). Exchangeble potassium was determined with a flame photometer after extracting k from the soil with 1N ammonium –acetate at pH 7 as described by Hesse (1971).

3.7. Data Collection and Measurements

3.7.1. Growth parameters

Days to maturity: Days to maturity was recorded when the 50% of the vines started to senescence in the net plot area.

Plant height (cm): Plant height was measured as the distance in cm from the soil surface to the top most growth point of aboveground at full maturity. Twenty plants were randomly taken from the net plot area for recording the plant height.

Leaf area index: Five plants (hills) from each plot were randomly selected and tagged. Leaf area index was estimated treatment wise by using the formula as given by (Sestak *et al.,* 1971).

$$LAI = \frac{\text{Leaf area (cm2/plant)}}{\text{Land area (cm2/plant)}}$$

Stem number per hill: The number of stems emerging from each seed tuber (hill) was counted from randomly selected five plants.

3.7.2. Yield components and yield

Total tuber number per plant: This was counted as the sum of marketable and unmarketable tuber from the net plot.

Average tuber weight (g): This was determined at harvest by dividing the weight of all tubers obtained from randomly taken five plants by the total number of tubers.

Tuber size distribution in number(%): It is the proportional number of tubers size categories which was taken at harvest.All tubers from net plot area plants were categorized in to small (25-39g); medium (40-75g), and large (>75g). Then each of these categories was counted, and the proportion of the number of each tuber category was expressed as a percentage (Lung'aho *et al.,* 2007)

Tuber size distribution in weight (%): It is the proportional weight of tubers size categories which was taken at harvest. All tubers from plants in the central rows of each plot were categorized into small (25-39 g); medium (40-75 g), and large (> 75 g) according to Lung'aho *et al*. (2007). Then each of these categories was counted, and the proportion of the weight of each tuber category was expressed as a percentage.

Marketable tuber number: The number of tubers which are free from diseases, insect pests, and greater than or equal to 25g in weight were determined by counting.

Total biomass (g): This refers to the fresh weight of leaves, stems, roots, stolons, and tubers. It was determined from 10 randomly taken plants from the central rows just before senescence.

Unmarketable tuber number: The numbers of tubers that were diseased and small-sized were determined by counting.

Marketable tuber yield (t/ha): The average mass of tubers which were free from diseases, insect pests, and greater than or equal to 25g in weight were recorded and expressed in t/ha.

Unmarketable tuber yield (t/ha): The average weight of tubers that were diseased and small-sized (<25g) were recorded.

Total tuber yield (t/ha): At harvest the total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tubers and expressed in t/ha.

Harvest index: This refers to the ratio of the dry weight of the tubers to the dry weight of the total biomass; including the tubers .It was determined from five randomly taken plants at harvest. The tubers were taken from all the five plants, washed with water, and sliced into thin (about 3mm) pieces. The sliced tubers were pre-dried in the sun by thiny spreading them in an open air on an aluminum foil or on any dry surface to dissipate excess moisture. The partially dried tubers were then be wrapped up in paper and dried in an oven until constant weight is obtained. The haulms, leaves, and all other plant parts of the five plants were also dried in the same way. Then, harvest index was computed by dividing the dry weight of the tubers by the dry weight of the total biomass.

3.7.3. Quality parameters

Specific gravity of tubers (gcm^{-3}): This was determined by the weight in air/weight in water method. Five kg tubers of all shapes and sizes were randomly taken from each plot. The selected tubers were washed with water. The samples were then first weighted in air and then re-weighted suspended in water. Specific gravity was then calculated using the following formula (Fong and Redshaw, 1973; Kleinkopf *et al*., 1987)

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{weight in water}}$$

Tuber dry matter content (%): Five fresh tubers were randomly selected from each plot and weighted at harvest. The tubers were then be sliced and dried in an oven at 65^0C until a constant weight is obtained. The dry weight was recorded and the dry matter percent was calculated according to Williams and Woodbury (1968).

*Dry matter (%) =weight of sample after drying (g)/initial weight of sample (g)*100*

3.8. Statistical Analysis

The data were subjected to analysis of variance by SAS software. Significance of differences between samples were separated using the least significance difference (LSD) at the alpha level of = 0.05. Correlation analysis was also done to determine the relationship among yield and yield components of the plant. The results of statistical analysis are shown in the tables.

4. RESULTS AND DISCUSSION

4.1. Selected Physicochemical Properties of the Soil of the Experimental Site

The results of the laboratory analysis of some selected physiochemical properties of the soil of experimental site are presented in the Appendix Table 1. Soil analysis results before planting showed that the soil is loam in texture and it was found to be strongly acidic in reaction with a pH of 4.35. Furthermore, according to Landon (1991), the experimental soil has medium CEC, medium total N, low K and medium organic matter. Such findings further signify that the soils require external application of nutrients according to recommendation for the crops grown. According to the classification limit set by Marx (1996), the soil is medium in soil available P (16.85 ppm).

4.2. Crop Phenology and Growth

4.2.1. Days to maturity

The combination of different rates of recommended dose of inorganic fertilizers with various levels of organic manures (farmyard manure, wood ash and compost) did not have a significant effect on days to maturity (Appendix Table 2). The result of the current experiment did not agree with the findings of Hegde and Dwivedi (1993) who reported that integration of organic manure with inorganic fertilizers hasten maturity period of the crop.

4.2.2. Plant height

The analysis of variance of plant height showed highly significant differences ($p<0.01$) for the combination of organic and inorganic fertilizers (Appendix Table2).

The plant height varied in the range of 48.80 – 62.36cm (Table 1). The tallest plants (62.36 cm) were recorded in the treatment 2 t/ha wood ash (WA) + 100% recommended dose of fertilizer (RDF) which was found to be statistically in parity with 2.0 t/ha WA + 5.0 t/ha farmyard manure (FYM) + 100% RDF, 2.0 t/ha WA + 5.0

t/ha compost (C) + 100% RDF, 2.0 t/ha WA + 5.0 t/ha FYM + 5.0 t/ha C + 100% RDF, 5.0 t/ha FYM + 50% RDF, 100% RDF and 5.0 t/ha C + 50% RDF. The shortest plants (48.80cm) were observed with the application of 2 t/ha WA along with 5.0 t/ha of FYM. The results showed that application of 4 t/ha WA, 10 t/ha FYM and 10 t/ha C alone and the combined application of either 5 t/ha (50 %) FYM or 5 t/ha (50%) C with 2 t/ha (50 %) WA as well as the combined application of 2 t /ha WA with 50 % of RDF did not prove significantly better than 2.0 t/ha WA + 100% RDF application. Moreover, application of 2 t/ha WA with either 5 t/ha FYM or 5 t /ha C and 50% of the RDF had no pronounced effect on plant height. However, when WA was combined with 100% RDF either alone or in combination with 5 t FYM/C there was an increase in plant height. This may suggest that the application of WA had no significant role in altering the plant height. The lower plant height with sole application of FYM or C might be due to their slow decomposition thus resulting in less availability of nutrients for the plant uptake.

Generally it was observed that treatments that received both organic and inorganic fertilizer produced plants with more height as compared to plants in unfertilized plot. The increase in plant height in the presence of inorganic fertilizer might be due to better availability of nutrients and the inorganic fertilizer in combined application with FYM/C might have enhanced the decomposition of organic sources thus the increased supply of nutrients for increasing the cell division and elongation. The current experiment result corroborates the findings of Gonzalez *et al.* (2001) who reported that organic manure and inorganic fertilizer supplied all the essential nutrients at seedling stage resulting in an increase of measured variables like plant height. Bwembya and Yerovun (2001) and Najm *et al*. (2010) also reported the combined effect of organic fertilizer and inorganic fertilizer on the plant height was significant.

4.2.3. Leaf area index

The perusal of the data with respect to leaf area index indicated significant difference among the treatments (Appendix Table 2). The mean values of the leaf area index observed to be in the range of 4.85 – 8.94 (Table 1). Among the treatments, maximum leaf area index was recorded in the treatment 2 t/ha WA + 5 t/ha C + 5 t/ha of FYM + 100% RDF (8.94) which was significantly higher than the leaf area obtained in the control, 4.0 t/ha WA , 10.0 t/ha C, 2.0 t/ha WA + 5.0 t /ha FYM, 2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF, 5.0 t/ha C + 50% RDF, 5.0 t /ha FYM + 50% RDF, 2.0 t/ha WA + 50% RDF and 2.0 t/ha WA + 5.0 t/ha C. This increase in leaf area index might be due more availability and up take of nutrients. Lowest leaf area index value (4.85) was observed in the treatment treated with 5 t/ha C + 50% RDF. Furthermore, the results of the present study could probably be attributed to the beneficial effect integrated fertilizer use and the macro as well as micro nutrients supplied through FYM (Shaban and Omer, 2006) and increased availability of plant nutrients (Kundu *et al*., 2007). The result of the current experiment corroborates the finding of Matiwos (2011) who reported the integrated nutrient management practices significantly influenced leaf area index.

Table 1**.** Days to maturity ,plant height (cm) and leaf area index as influenced by integrated soil amendment practices in potato at Jimma Arjo during 2013

Treatment	Days to maturity	Plant height(cm)	Leaf area index
Control	101.7	50.93^{de}	6.05^{b-d}
2.0 t/ha WA + 5.0 t /ha FYM	101.0	48.80^{e}	6.66^{bc}
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	101.7	51.60^{de}	7.36^{a-c}
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	101.7	54.53^{b-e}	5.77^{cd}
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	101.7	59.90^{ab}	7.72^{ab}
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	101.3	61.53^{ab}	7.24^{a-c}
2.0 t/ha WA + 100% RDF	101.0	62.36^{a}	7.61^{ab}
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	100.7	59.86^{ab}	8.94^{a}
10.0 t/ha C	101.7	49.86^{de}	6.77^{bc}
10.0 t/ha FYM	102.3	51.90^{c-e}	7.63^{ab}
4.0 t/ha WA	101.3	51.50^{de}	6.38^{b-d}
100% RDF	101.7	58.90^{a-c}	7.73^{ab}
5.0 t/ha C + 50% RDF	102.0	56.43^{a-d}	4.84^{d}
5.0 t /ha FYM + 50% RDF	100.0	59.46^{ab}	6.63^{bc}
2.0 t/ha WA + 50% RDF	101.0	54.66^{b-e}	6.51^{b-d}
2.0 t/ha WA + 5.0 t/ha C	101.7	50.06^{de}	6.67^{bc}
LSD (0.05)	NS	7.05	1.75
CV (%)	2.10	7.69	15.30

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 % level of LSD test. RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash

4.2.4. Total fresh biomass (g)

The analysis of variance showed a highly significant effect of treatments on total fresh biomass (Appendix

Table2). The results (Table 2) indicated that the highest total fresh biomass (748.69g/plant) was obtained from the combined application of 2 t/ha WA + 5 t/ha FYM + 50% RDF which was significantly higher than the total fresh biomass obtained in the control, application of WA, FYM and C alone, combined application 5 t/ha FYM, 5 t /ha C with 50% RDF and 2 t/ha WA with 5 t /ha FYM 5 t/ha C. The lowest total fresh biomass (618.48 g/ plant) was recorded in the integration of 2 t/ha WA + 5 t/ha C. Similar results were reported by Ambecha (2002) in case of sweet potato.

Table 2. Stem number per hill and total fresh biomass (g/plant) as influenced by integrated soil amendment practices in potato crop at Jimma Arjo during 2013

Treatment	Stem number per hill	Total fresh biomass yield (g/plant)
Control	5.23[cd]	630.71[de]
2.0 t/ha WA + 5.0 t /ha FYM	5.56[b-d]	687.83[e-e]
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	5.33[cd]	708.17[a-c]
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	5.96[b-d]	748.69[a]
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	7.46[a]	708.60[a-c]
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	5.86[b-d]	680.17[a-e]
2.0 t/ha WA + 100% RDF	5.80[b-d]	729.69[ab]
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	6.43[a-c]	691.97[a-d]
10.0 t/ha C	5.30[cd]	650.50[c-e]
10.0 t/ha FYM	5.23[cd]	658.84[c-e]
4.0 t/ha WA	5.10[d]	678.17[b-e]
100% RDF	6.73[ab]	741.13[ab]
5.0 t/ha C + 50% RDF	5.93[b-d]	627.99[de]
5.0 t /ha FYM + 50% RDF	5.03[d]	650.88[c-e]
2.0 t/ha WA + 50% RDF	5.76[b-d]	692.28[a-d]
2.0 t/ha WA + 5.0 t/ha C	4.93[d]	618.48[e]
LSD(0.05)	1.27	69.67
CV (%)	13.33	6.14

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 % level of LSD test. RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash

4.2.5. Stem number per hill

The stem number per hill was significantly influenced by the application of organic and inorganic fertilizers ($p<0.05$). The number of stems per hill with the application of different treatments varied from 4.93 to 7.46. The highest stem number (7.46 per hill) was produced by the integrated application of 2 t /ha WA + 5 t/ha C + 100% RDF. However, it was statistically in parity with 100% RDF and 2.0 t/ha WA + 5.0 t/ha C + 100% RDF. The plants that received 2.0 t/ha WA + 5.0 t/ha C had the minimum number of stems/hill which did not differ significantly with all the treatments except the above mentioned treatments. The current finding is in disagreement with the observation of Anand and Krishnappa (1989) who stated that the number of stems/ hill did not differ significantly due to the application of different levels of N and K as well as their interaction. In general this trait was not significantly influenced by most of the treatments, possibly because stem number may be influenced by other factors such as storage condition of tubers, number of viable sprouts at planting, sprout damage at the time of planting and growing conditions (Allen, 1978), physiological age of the seed tuber (Iritani, 1968), variety (Lynch and Tai, 1989) and tuber size (Harris, 1978).

4.3. Some Major Yield Component of Potato

4.3.1. Total tuber number per hill

Analysis of variance for number of total tubers per hill showed significant (<0.05) differences among various fertilizer combinations (Appendix Table 3). The number of tubers per plant was maximum (9.46) differed significantly where in the application of 100% of recommended dose of fertilizer (RDF) combined with 2 t/ha of wood ash recorded significantly maximum number of tubers per hill (9.46) with the combined application of 2.0 t/ha WA + 100% RDF whereas the lowest total tuber number per hill (7.90) was observed in the plots that received 2 t/ha WA + 5 t/ha C. The increase in number of average tuber with the combined use of different organic and inorganic fertilizer might be due to the increased photosynthetic activity and translocation of photosynthate to the root, which might have helped in the initiation of more stolon in potato (Annad and Krishinappa, 1989). Tuber number is also determined by the number of stems produced which in turn depends up on the tuber size and variety as reported by Ebwongu *et al.* (2001). However, contradicting results have been reported regarding the effects of fertilizer on the tuber number. The observed conflicting results may be linked to the difference in season, inherent nutrient status of a soil and location which could have exerted their effects in determining the number set by the potato plant. Tuber number is not an important yield limiting component while studying mineral nutrition (Sharma and Arora, 1987; De La Morena *et al.,* 1994; Lynch and Rowberry, 1997) that could be due to the inverse association between tuber number and average tuber weight (De La Morena *et al.*, 1994).

4.3.2. Potato tuber yield in different size number

4.3.2.1. Large tuber size number (%)

The mean value of large tuber size number showed significant difference among the treatments (Table 3). The mean values were observed to be in range of 21.4 to 23.2% wherein the maximum large sized tuber percentage was found in response to the application of 2 t/ha WA + 5 t/ha C + 50% of RDF and the minimum with 2 t/ha WA + 5 t/ha C. The application of 2 t/ha WA + 5 t/ha C + 50% of RDF had no significant difference in the percentage large tuber size with the combination of 2 t/ha WA + 50% RDF, 4 t/ha WA, 100% RDF, 5 t/ha FYM + 50% RDF, 2 t/ha WA + 100% RDF, 10 t/ha FYM, and 5.0 t/ha C + 50% RDF which were on par with each other.

Table 3. Total tuber number hill and different tuber size number as influenced by integrated soil amendment practices in potato crop at Jimma Arjo during 2013

Treatment	Total tuber number per hill	Large tuber size number (%)	Medium tuber size number (%)	Small tuber size number (%)
Control	8.46^{c-e}	22.0^{b-e}	59.5^{a-c}	18.5^{d-f}
2.0 t/ha WA + 5.0 t /ha FYM	8.63^{b-e}	22.2^{b-e}	53.3^{d}	23.4^{ab}
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	8.83^{a-d}	23.2^{a}	58.3^{bc}	18.5^{d-f}
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	9.36^{ab}	22.2^{b-e}	57.7^{bc}	20.8^{b-e}
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	8.70^{b-d}	21.7^{de}	58.3^{bc}	20.0^{c-e}
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	8.86^{a-d}	21.8^{de}	55.5^{cd}	22.8^{a-c}
2.0 t/ha WA + 100% RDF	9.46^{a}	22.3^{a-e}	53.6^{d}	24.1^{ab}
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	9.16^{a-c}	21.8^{de}	56.2^{b-d}	22.0^{a-c}
10.0 t/ha C	8.43^{c-e}	21.9^{c-e}	53.4^{d}	24.8^{a}
10.0 t/ha FYM	9.03^{a-d}	22.4^{a-d}	58.0^{bc}	19.7^{c-e}
4.0 t/ha WA	8.46^{c-e}	22.8^{a-c}	56.0^{b-d}	21.2^{b-c}
100% RDF	9.10^{a-c}	22.6^{a-d}	59.8^{ab}	17.5^{ef}
5.0 t/ha C + 50% RDF	8.66^{b-d}	22.4^{a-d}	59.4^{a-c}	18.3^{d-f}
5.0 t /ha FYM + 50% RDF	8.33d^{e}	22.5^{a-d}	56.6^{b-c}	20.9^{b-e}
2.0 t/ha WA + 50% RDF	8.50^{c-e}	22.9^{ab}	55.6^{cd}	21.5^{a-d}
2.0 t/ha WA + 5.0t/ha C	7.90^{e}	21.4^{e}	62.9^{a}	15.7^{f}
LSD(0.05)	0.76	0.93	4.06	3.35
CV (%)	5.26	2.60	4.27	9.78

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 % level of LSD test. RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash.

4.3.2.2. Medium tuber size number (%)

Statistically highly significant variations (P<0.01) were observed among different fertilizer treatments on percentage of medium tuber size number (Appendix Table3). The medium tuber size number ranged from 53.29 (2.0 t/ha WA + 5.0 t /ha FYM) to 62.88%. The maximum mean medium tuber size number obtained with the combined application of 2.0 t/ha WA + 5.0 t/ha C had no significant difference with 100% RDF, 5.0 t/ha C + 50% RDF and the control.

4.3.2.3. Small tuber size number (%)

Analysis of variance showed that small tuber size number was high significantly (p<0.001) affected by various organic and inorganic fertilizers and their combinations (Appendix Table 4). The maximum small tuber size number (24.75%) was obtained with the application of 10 t/ha C while the minimum percentage of small size tuber number was found in response to the application of 2.0 t/ha WA + 5.0 t/ha C (15.7%) which was statistically at par with 5.0 t/ha C + 50% RDF, 100% RDF, 2.0 t/ha WA + 5.0 t/ha C + 50% RDF and the control. However, in general the extent of variation among the treatments was more. The maximum and the minimum small size tuber number (%) were found in treatments involving10 t/ha C alone and the combination of 2.0 t/ha WA + 5.0 t/ha C, respectively which may probably be due to the total number of tubers per hill. Among the growth conditions environmental factors that favor cell division and cell expansion such as mineral nutrition, optimum water supply were reported to enhance tuber size. But in this study even under higher nutrient supply the percentage of small tuber remained comparatively higher.

4.3.3. Potato tuber yield in different size weight

4.3.3.1. Large tuber size weight (%)

The highest large tuber size weight was obtained without fertilizer application (control) which was 54.8% and it was statistically in parity with the weight obtained with the application of the application of 2.0 t/ha WA + 5.0 t/ha C + 50% RDF, 2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF, 10.0 t/ha C, 10.0 t/ha FYM, 4.0 t/ha WA, 100% RDF, 5.0 t/ha C + 50% RDF, 5.0 t /ha FYM + 50% RDF and 2.0 t/ha WA + 50% RDF. In general the large tuber size weight was more than the medium size tuber weight in all the above treatments except 2.0 t/ha WA + 5.0 t/ha C + 50% RDF, 2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF and 10.0 t/ha C.

4.3.3.2. Medium tuber size weight (%)

The effect of organic and inorganic fertilizers was significant ($p<0.05$) on medium tuber size weight (Appendix Table 3). The results showed the highest medium size tuber weight (62.03%) with the application of 2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C + 100% RDF and the lowest (37.10%) was obtained in control. A close perusal of the data (Table 5) revealed that in general, the treatments which had more large tuber size weight had lower medium tuber size weight and vice versa.

4.3.3.3. Small tuber size weight (%)

The variation in the small tuber size weight though was visualized narrow i.e. between 7.8% to 8.8 %, yet significant differences existed between the treatments. The lowest small size tuber weight was found with the application each of 5.0 t /ha FYM + 50% RDF and 2.0 t/ha WA + 5.0t/ha C, while the highest was with the application each of 2.0 t/ha WA + 5.0 t /ha FYM and 2.0 t/ha WA + 5.0 t/ha C + 100% RDF (Table 5). However, the treatments had more pronounced effect on large and medium size tuber weight.

Table 4. Different tuber size weight as influenced by integrated soil amendment practices in potato crop at Jimma Arjo during 2013

Treatment	Large tuber size weight (%)	Medium tuber size weight (%)	Small tuber size weight (%)
Control	54.80^{a}	37.10^{c}	8.10^{b-d}
2.0 t/ha WA + 5.0 t /ha FYM	39.50^{bc}	51.69^{ab}	8.80^{a}
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	43.46^{ab}	48.23^{bc}	8.30^{a-d}
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	42.83^{ab}	48.86^{bc}	8.30^{a-d}
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	39.35^{bc}	51.84^{ab}	8.80^{a}
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	38.89^{bc}	53.21^{ab}	7.90^{cd}
2.0 t/ha WA + 100% RDF	40.34^{bc}	51.25^{ab}	8.40^{a-c}
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	29.77^{c}	62.03^{a}	8.20^{b-d}
10.0 t/ha C	44.01^{ab}	47.92^{bc}	8.07^{b-d}
10.0 t/ha FYM	49.32^{ab}	42.18^{bc}	8.50^{ab}
4.0 t/ha WA	49.74^{ab}	42.19^{bc}	8.07^{b-d}
100% RDF	47.73^{ab}	44.37^{bc}	7.90^{cd}
5.0 t/ha C + 50% RDF	49.15^{ab}	42.41^{bc}	8.43^{a-c}
5.0 t /ha FYM + 50% RDF	49.63^{ab}	42.56^{bc}	7.80^{d}
2.0 t/ha WA + 50% RDF	48.06^{ab}	43.54^{bc}	8.40^{a-c}
2.0 t/ha WA + 5.0t/ha C	39.27^{bc}	52.93^{ab}	7.80^{d}
LSD(0.05)	12.11	11.96	0.58
CV (%)	15.40	14.13	4.23

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 % level of LSD test. RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash

4.3.4. Marketable and unmarketable tuber number

Integration of organic and inorganic fertilizer highly significantly ($p<0.01$) affected both marketable and unmarketable tuber number (Appendix Table 3). The combined application of 2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF gave the highest (80.05%) proportion of marketable tubers but this treatment had no significant difference with 2.0 t/ha WA + 5.0 t /ha FYM, 2.0 t/ha WA + 5.0 t/ha C + 100% RDF, 2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF, 100% RDF, and 5.0 t/ha C + 50% RDF. It is obvious that in the treatments which had higher marketable tuber number will have lower unmarketable tuber number thus, the minimum marketable tuber number was found in the control (73.03%). The current experiment was corroborates the finding of Daniel (2007) who reported the lowest marketable tuber number was obtained in the control treatment.

Table 5. Average tuber weight (g), marketable and unmarketable tuber number (%) of potato crop as influenced by integrated soil amendment practices at Jimma Arjo during 2013

Treatment	Marketable tuber number (%)	Unmarketable tuber number (%)	Average tuber weight(g/tuber)
Control	73.03[f]	26.97[a]	50.85[cd]
2.0 t/ha WA + 5.0 t /ha FYM	77.95[a-c]	22.05[d-f]	56.54[a-c]
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	76.67[b-e]	23.33[b-e]	57.49[ab]
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	76.67[b-e]	23.32[b-e]	58.55[ab]
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	77.18[a-d]	22.81[c-f]	58.49[ab]
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	78.20[ab]	21.79[ef]	54.16[a-d]
2.0 t/ha WA + 100% RDF	74.95[b-f]	25.04[a-e]	56.01[a-c]
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	80.05[a]	19.94[f]	53.64[a-d]
10.0 t/ha C	74.41[d-f]	25.57[a-c]	53.37[a-d]
10.0 t/ha FYM	76.39[b-e]	23.61[b-e]	50.80[cd]
4.0 t/ha WA	73.50[ef]	26.49[ab]	56.41[a-c]
100% RDF	77.54[a-d]	22.45[c-f]	59.46[a]
5.0 t/ha C + 50% RDF	77.57[a-d]	22.42[c-f]	49.35[d]
5.0 t /ha FYM + 50% RDF	73.40[ef]	26.59[ab]	53.92[a-d]
2.0 t/ha WA + 50% RDF	75.93[b-f]	24.06[a-e]	58.04[ab]
2.0 t/ha WA + 5.0 t/ha C	74.74[c-f]	25.25[a-d]	53.04[b-d]
LSD(0.05)	3.34	3.34	6.23
CV (%)	2.72	8.43	6.86

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 %v level of LSD test. RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash

4.3.5. Average tuber weight

The mean tuber weight showed significant difference among the treatments (Appendix Table3). The highest tuber weight (59.46 g/tuber) was obtained with the application of 100% RDF which was significantly higher than that obtained with the application of 2.0 t/ha WA + 5.0 t/ha C, 10.0 t/ha FYM, 5.0 t/ha C + 50% RDF and the control. The increase in average tuber weight with the supply of fertilizer nutrients could be due to more luxuriant growth and higher supply of photo assimilates which helped in producing larger size tubers, hence resulting in higher yields (Patricia and Bansal, 1999). In other words, the increased size and duration of the haulm stemming from improved supply of nutrients might have favored the tuber weight as observed by Peter and Hruska (1988). The current experiment result was corroborates the findings of Matiwos (2011) who reported that integrated nutrient management practices significantly increased average tuber weight. The increase in number of average tuber with the combined use of organic and inorganic fertilizer might be due to the increased photosynthetic activity and translocation of photosynthate to the root, which might helped in the initiation of more stolon in potato (Annad and Krishinapp, 1989). Tuber number is also determined by the number of stems produced which in turn depends upon the tuber size and variety as reported by Ebwongu *et al.* (2001). Conflicting to the findings of the present study, Daniel (2007) found no significant influence of organic fertilizer application on average tuber weight.

4.4. Tuber Yield

4.4.1. Marketable and unmarketable tuber yield (t/ha)

The integration of different rates of recommended dose of inorganic fertilizers with various rates of organic manures (FYM, WA and C) showed significant effect on both marketable and unmarketable tuber yield (Appendix Table 3).

The mean value of marketable tuber yield varied from 9.50 t/ha to 12.74 t/ha in respect of all the treatments. Maximum marketable tuber yield (12.74 t/ha) was recorded with the combined application of 2 t/haWA+5 t/ha FYM+100% RDF which was statistically at par with 100% RDF, 2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF, 2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF, 2.0 t/ha WA + 5.0 t/ha C + 100% RDF, 2.0 t/ha WA + 50% RDF, 2.0 t/ha WA + 100% RDF, 5.0 t/ha C + 50% RDF and 2.0 t/ha WA + 5.0 t/ha C + 50% RDF. The magnitude of marketable tuber yield increase of these treatments was 34.1, 33.7, 30.1, 27.7 27.3, 25.7, 24.8, 21.1 and 17.4%, respectively over the control. The increased yield with some of the organic and inorganic fertilizers combinations that included wood ash also might be due to positive effect of ash on soil texture, aeration, water holding capacity and cation exchange capacity as reported by Demeyer *et al*. (2001). It has also been observed that if the nitrogen is limited the application of ash may not be beneficial (Moilanen *et al*., 2006). In this study also the combined application of wood ash with organic sources (compost and farmyard manure) in the absence of inorganic fertilizer did not prove much beneficial in promoting the tuber yield. However, it needs extensive further studies as it behaved differentially in different combinations. The integrated use of organic and inorganic fertilizers though influenced the marketable tuber yield to a variable extent but the results of this experiment confirms the observations of Sanchez and Jam (2000) who reported that integration of organic and inorganic inputs sustained crop production due to positive interaction and complementarities between them. It has been observed that addition of manure increases soil water holding capacity and this means that nutrient would be made available to crops where manure has been added to the soil (Costa *et al*., 1991). Fuchs *et al.* (1970) also reported that nutrients from mineral fertilizers enhance the establishment of crops while those from mineralization of organic manure promoted yield when both fertilizers were combined. Murwira and Kirchman (1993) observed that nutrient use efficiency might be increased through the combination of manure and mineral fertilizer.

Table 6. Marketable, unmarketable, total tuber yield (t/ha) and harvest index of potato crop as influenced by integrated soil amendment practices at Jimma Arjo during 2013

Treatment	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ha)	Harvest index
Control	9.50f	1.90[c-e]	11.40[f]	0.56
2.0 t/ha WA + 5.0 t /ha FYM	10.36[c-f]	2.63[a-d]	12.99[c-e]	0.60
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	11.15[a-f]	3.27[a]	14.42[a-c]	0.57
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	12.36[a-c]	2.82[a-d]	15.18[a]	0.56
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	12.09[a-d]	2.88[a-c]	14.97[a]	0.49
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	12.74[a]	1.99[b-e]	14.73[a]	0.68
2.0 t/ha WA + 100% RDF	11.86[a-e]	2.71[a-d]	14.57[ab]	0.62
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	12.13[a-d]	2.87[a-c]	15.01[a]	0.54
10.0 t/ha C	9.68[f]	1.97[c-e]	11.65[ef]	0.65
10.0 t/ha FYM	9.96ef	2.41[a-d]	12.37[d-f]	0.65
4.0 t/ha WA	9.93ef	2.22[b-e]	12.31[d-f]	0.63
100% RDF	12.40[ab]	1.42[e]	13.83[a-c]	0.65
5.0 t/ha C + 50% RDF	11.50[a-f]	2.82[a-d]	14.32[a-c]	0.49
5.0 t /ha FYM + 50% RDF	10.68[b-f]	2.54[a-d]	13.23[b-d]	0.52
2.0 t/ha WA + 50% RDF	11.94[a-e]	2.96[ab]	14.91[a]	0.65
2.0 t/ha WA + 5.0 t/ha C	10.32[d-f]	1.88[de]	12.20[d-f]	0.55
LSD(0.05)	2.01	0.98	1.45	NS
CV (%)	10.86	24.46	6.57	18.54

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 %v level of LSD test .RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash

Maximum unmarketable tuber yield (3.27t/ha) was recorded from the plots amended with 2 t/haWA+5 t/ha C+50% RDF whereas the sole application of inorganic fertilizer (100% RDF) resulted minimum unmarketable tuber yield (1.42 t/ha).

4.4.2. Total tuber yield (t/ha)

The total tuber yield (marketable + unmarketable) of potato was increased high significantly due the application of organic and inorganic fertilizers (Appendix Table 3). The mean yield ranged between 11.40 to 15.18 t /ha. The highest total tuber yield (15.18 t /ha) was obtained with the application of 2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF which was followed by the application of 2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF, 2.0 t/ha WA + 5.0 t/ha C + 100% RDF and 2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF. The lowest total tuber yield (11.41t/ha) was recorded in the control treatment.

Therefore, the maximum tuber yields in these treatments may be due to increased tuber weight, tuber girth and higher proportion of large and medium sized tuber. These results are in confirmation with Sood (2007) who observed higher potato tuber yield under integrated use of organic (FYM) and inorganic source. Shivasupiramanian and Malik (1989) also observed increased tuber yield in potato crop when the crop was supplied with sheep manure. Sibale and Smith (1997) who reported a significant increase in tuber yield with increasing organic manure and mineral fertilizers and attributed it to higher nutrient availability and uptake with higher rates of both fertilizer rates. Apart from supplying nutrients, manure provides valuable organic matter to help improve soil physical properties and increase the activity of beneficial soil microbes (Chen *et al*., 2001). Charreau (1991) and Murwira *et al*. (1985) also stated that higher crop yields are achieved with the same amount of nutrients when supplied through combined use of organic and inorganic fertilizers than mineral fertilizer alone. The interaction effect of small amounts of inorganic fertilizer and organic materials could meet the mineral fertilizer requirements of crops for maximum yields. Many studies in Zimbabwe indicated that manure alone generally produced low crop yields (Mugwira, 1985).

4.5. Harvest Index

Harvest index as influenced by different nutrient management practices did not show significant difference (Appendix Table 3).The current experiment was confirmed with the finding of Matiwos (2011) who reported harvest index by integrated nutrient management practice did not show significance difference.

4.6. Quality Attributes

4.6.1. Tuber dry matter

The analysis of variance (Appendix Table 4) pertaining to the influence of nutrient management practices on tuber dry matter indicated high significant difference ($p<0.001$) among the treatments. The mean values on tuber dry matter were observed to be in range of 15.41 to 30.80 % (Table7). The maximum tuber dry matter (30.80%) was recorded in treatment that received 4 t/ha wood ash which was significantly higher than the dry matter obtained under the influence of control, 2.0 t/ha WA + 5. 0 t /ha FYM, 2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF, .0 t/ha WA + 5.0 t/ha C + 100% RDF, 2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF, 5.0 t/ha C + 50% RDF and 2.0 t/ha WA + 5.0t/ha C. The organic manure may have essential nutrients that increase tuber dry matter. Though there was inconsistency in the results obtained but the integrated nutrient supply increased dry matter yield of potato as reported by Olani (2002).

Table 7. Tuber dry matter and specific gravity of potato crop as influenced by integrated soil amendment practices at Jimma Arjo during 2013

Treatment	Tuber dry matter (%)	Specific gravity
Control	20.93^{cd}	1.07
2.0 t/ha WA + 5.0 t /ha FYM	28.16^{b}	1.06
2.0 t/ha WA + 5.0 t/ha C + 50% RDF	30.33^{ab}	1.08
2.0 t/ha WA + 5.0 t /ha FYM + 50% RDF	21.56^{cd}	1.07
2.0 t/ha WA + 5.0 t/ha C + 100% RDF	15.41^{e}	1.08
2.0 t/ha WA + 5.0 t /ha FYM + 100% RDF	29.69^{ab}	1.07
2.0 t/ha WA + 100% RDF	29.45^{ab}	1.08
2.0 t/ha WA + 5.0 t /ha FYM + 5.0 t/ha C +100% RDF	22.61^{c}	1.07
10.0 t/ha C	30.43^{ab}	1.08
10.0 t/ha FYM	30.41^{ab}	1.07
4.0 t/ha WA	30.80^{a}	1.09
100% RDF	30.00^{ab}	1.06
5.0 t/ha C + 50% RDF	16.30^{e}	1.08
5.0 t /ha FYM + 50% RDF	19.50^{d}	1.07
2.0 t/ha WA + 50% RDF	30.00^{ab}	1.08
2.0 t/ha WA + 5.0t/ha C	19.40^{d}	1.08
LSD(0.05)	2.55	NS
CV	6.05	1.57

Means within the same column followed by the same letter or by no letters do not differ significantly at the 5 %v level of LSD test;.RDF=recommended dose of fertilizer, C=compost, FYM=farmyard manure, WA=wood ash

4.6.2. Specific gravity

The integrated use of organic and inorganic fertilizers exhibited no significant difference among the treatments in terms of specific gravity of tubers (Appendix Table 4). Similarly, Robert and Cheng (1988) obtained no significant difference in specific gravity of tubers due to fertilizer especially nitrogen application. The current findings are not in agreement with the finding of Zende *et al.* (1998) who observed that application of vermicompost increased tuber quality parameters like specific gravity. Inconsistent and contradictory results on tuber specific gravity were obtained by different workers due to variety and interaction effect of organic and inorganic fertilizers. The reason could be due to differences in variety used and soil nutrient status and management practices (Chapman *et al.,* 1992).

4.7. Association of Characters

The estimates of correlation coefficients between each pair of the characters studied are presented in Appendix Table 5, 6 and7. Results on simple correlation coefficients revealed that both marketable and total tuber yield exhibited highly significant ($p<0.01$) positive correlation with some growth characters such as plant height ($r=0.62^{**}$), total fresh biomass ($r=0.65^{**}$) and number of stem per hill r= (0.47^{**}) whereas leaf area index ($r=0.12$) did not have a significant correlation both for marketable tuber yield and total tuber yield. Total fresh biomass positively and high significantly correlated to plant height ($r=0.45^{**}$) and leaf area index ($r=0.30^{*}$) while stem number per hill positively and significantly correlated to leaf area index ($r=0.34^{*}$) and total fresh biomass ($r=0.35^{*}$). Beukema and Van der Zag (1979) and Rasui *et al.* (1995) also found high positive association of tuber yield with growth characters such as plant height and leaf area. The positive and significant correlation coefficients(r values) between tuber yield and growth parameters indicated that tuber yield is greatly influenced by these growth parameters. Thus, any management practices that provide favorable influences on these variables are likely to enhance tuber yield.

Total tuber number per hill (r=0.45**) was positively and high significantly (P<0.01) correlated with marketable tuber yield whereas marketable tuber number (r=0.34*) was positively and significantly (p<0.05) correlated with marketable tuber yield. Unmarketable tuber number (r=-0.34*) was negatively and significantly (p<0.05) correlated to marketable tuber yield. Total tuber number per hill was positively and significantly correlated to marketable tuber number (r=0.30*) but negatively and significantly correlated with unmarketable tuber number(r=-0.30*).Medium tuber size number was positively and significantly correlated to large tuber size number(r=0.30*) but negatively and high significantly correlated with small tuber size number(r=-0.96***) whereas large tuber size weight negatively and high significant to medium tuber size weight(r=-0.99). Marketable tuber number was negatively and high significantly correlated to unmarketable tuber number(r=-1.00). Girma (2001) Birhuman and Maris(1993) also found a significant linear correlation between yield and yield components of potato.

5. SUMMARY AND CONCLUSIONS

The field experiment was carried out during 2013 at Jimma Arjo to study the effect of integrated soil amendment practices on growth and seed tuber yield of potato. Totally, there were sixteen different treatments consisting of different organic and inorganic fertilizers. The quantity of nutrients through organic sources were supplied in forms of farmyard manure, compost and wood ash .Inorganic major nutrients were supplied in the form of urea and DAP. Improved potato variety, Gudene used as the planting material. The experiment was laid out in randomized complete block design in a one way concept with three replications.

The results showed that integrated use of organic and inorganic fertilizer had significant effect on the potato growth parameters, plant height, leaf area index, total fresh biomass and stem number per hill. Tuber yield and its attributing characters like total tuber number per hill, average tuber weight, large tuber size number, medium tuber size number, small tuber size number, large tuber size weight, medium tuber size weight, small tuber size weight, marketable tuber number, unmarketable tuber number, marketable tuber yield, unmarketable tuber yield, total tuber yield and tuber dry matter were also significantly influenced. It was observed that integration of different organic and inorganic fertilizer had no significant influence on days to maturity, harvest index and specific gravity.

Application of 100% of the recommended dose of the fertilizer (RDF) + 2 t/ha of wood ash + 5 t/ha of compost resulted in the maximum stem number per hill, maximum small tuber size weight and maximum total tuber yield. However, application of 2 t/ha wood ash + 5 t/ha compost + 5 t/ha farmyard manure + 100% of recommended dose of fertilizer (RDF) gave the highest leaf area index, maximum total fresh biomass, medium tuber size weight, marketable tuber number and maximum total tuber yield. Integration of 2 t /ha wood ash + 100% of the recommended dose of fertilizer (RDF) resulted in the highest plant height and total tuber number per hill. Maximum marketable tuber yield was obtained in response to the application of 2 t/ha wood ash + 5 t/ha farmyard manure + 100% of the recommended dose of fertilizer whereas highest unmarketable tuber number and large tuber size weight was recorded in the control treatment. The maximum large, medium and small tuber size were observed in the treatment treated with 2 t/ha wood ash+ 5 t/ha compost+50% RDF, 2 t/ha wood ash+5t/ha compost and 10t /ha compost respectively. Maximum tuber dry matter and average tuber weight were recorded in the treatment received 4t/ha wood ash and 100% recommended dose of fertilizer respectively.

The marketable and total tuber yield was positively and significantly correlated with growth components like plant height, total fresh biomass and stem number per hill. Similarly the marketable and total tuber yield was positively and significantly correlated yield components like total tuber number per plant and marketable tuber number.

Generally the combination of organic and inorganic fertilizer showed better result in most of the parameter studied so in the future:

- Similar studies need to be done in various agro-climatic and soil condition for a number of seasons to generate more reliable information regarding the use of organic and inorganic fertilizer.
- The role of wood ash in promoting plant growth and yield needs extensive further studies as it behaved differentially in different combinations.
- There is a need to evaluate the response of different varieties of potato to integrated nutrient management practices.
- There is a need to study integrated nutrient management in potato under irrigated condition.
- The secondary and micro nutrients which influence yield and quality of potato need to be evaluated through integrated nutrient management.

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7. APPENDICES

Appendix Table 1**.** Selected physical and chemical properties of the soil of the experimental site of the study area

Parameter	value
Moisture content (%)	10.81
Sand (%)	45
Silt (%)	37
Clay (%)	18
Textural class	Loam
pH(1.2.5 soil:H_2O)	4.35
Total N (%)	0.14
Organic matter (%)	5.17
Available K(ppm)	21.84
Available P(ppm)	16.85
Cataion exchange capacity(cmol(+)/kg)	27.70
Exchangeable K(cmol(+)/kg)	0.46

Appendix Table 2. Analyses of variance for growth parameters of potato as influenced by organic and inorganic fertilizer

Parameter	Source			
	Replication DF=2	Treatment DF=15	Error DF=30	CV
DM	2.25NS	0.97NS	2.39	2.01
PH	30.16NS	64.18**	18	7.69
LAI	0.05NS	2.74*	1.11	15.30
TFB	2017.51NS	4788.42**	1754.81	6.14
SNPH	1.76*	1.40*	0.58	13.33

Where, DF=Degree of freedom, CV=Coefficient of variation, PH=Plant height, LAI=Leaf area index, TFB=Total fresh biomass and SNPH=Stem number per hill

Appendix Table 3. Analyses of variance for yield and yield components as influenced by organic and in organic fertilizer

Parameter	Source			
	Replication DF=2	Treatment DF=15	Error DF=30	CV
Total tuber number /hill	0.66*	0.50*	0.21	5.26
Average tuber weight	11.32NS	28.53*	14.06	6.86
Large tuber size number	0.01NS	0.69*	0.31	2.60
Medium tuber size number	8.07NS	20.61**	5.96	4.27
Small tuber size number	6.72NS	18.79***	4.06	9.78
Large tuber size weight	156.56*	114.82*	53.08	15.40
Medium tubers size weight	147.34NS	113.26*	51.71	14.13
Small tuber size weight	0.34NS	0.29*	0.12	4.23
Marketable tuber number	0.16NS	11.81**	4.05	2.72
Unmarketable tuber number	0.16NS	11.81**	4.05	8.43
Harvest index	0.06***	0.01ns	0.01	18.54
Marketable tuber yield	0.52NS	3.58*	1.47	10.86
Unmarketable tuber yield	0.13NS	0.77*	0.34	24.46
Total tuber yield	0.12NS	5.15***	0.76	6.57

DF=degree of freedom, CV=Coefficient of variation

Appendix Table 4. Analysis of variance for some selected tuber quality parameters as influenced by organic and inorganic fertilizer

Parameter	Source			
	Replication DF=2	Treatment DF=15	Error DF=30	CV
Tuber dry matter	10.14**	96.89***	2.35	6.05
Specific gravity	0.000009NS	0.00016ns	0.00027	1.57

Df=Degree of freedom, CV=Coefficient of variation

Appendix Table 5. Correlation coefficient between total tuber yield and growth characters in Potato

Character	PH	LAI	TFB	SNPH	TTY
PH		0.12ns	0.45**	0.28ns	0.62**
LAI			0.30*	0.34*	0.11ns
TFB				0.35*	0.65**
SNPH					0.47**
TTY					

PH= plant height, LAI= Leaf area index, TFB=Total fresh biomass, SNPH=Stem number per hill, TTY=Total tuber yield, n=48, *, and** indicates significant linear correlation at =p<0.05, **= p<0.01 respectively where as ns=non significance difference.

Appendix Table 6**.** Correlation coefficient between marketable tuber yield and growth characters in potato

Character	PH	LAI	TFB	SNPH	MTY
PH		0.12ns	0.15	0.28ns	0.61***
LAI			0.36*	0.34*	0.16ns
TFB				0.36*	0.42**
SNPH					0.49**
MTY					

PH= plant height, LAI= leaf area index, TFB=tuber fresh biomass, SNPH=stem number per hill, MTY=marketable tuber yield, n=48, *, and ** indicates significant linear correlation at p<0.05, *and p<0.01 respectively where as ns= indicates non significance difference at p<0.05.

Appendix Table 7**.** Correlation coefficient between marketable tuber yield and yield components of potato

No	Character	1	2	3	4	5	6	7	8	9	10	11
1	TTNPH											
2	LTSN	0.09ns										
3	MTSN	-0.15	0.30*									
4	STSN	0.16	0.09	-0.96***								
5	LTSW	-0.16	0.34	-0.01	-0.06							
6	MTSW	0.15	-0.35	0.02	0.05	-0.99***						
7	STSW	0.27	0.06	-0.16	0.14	-0.22	0.17					
8	ATW	0.16	0.11	-0.06	0.06	-0.08	0.08	0.05				
9	MTN	0.30*	0.11	0.0006	-0.09	0.07	-0.26	0.25	0.23			
10	UMTN	-0.30*	-0.007	0.09	-0.07	0.26	-0.25	-0.23	-0.11	-1.00***		
11	MTY	0.45**	0.02	0.03	-0.04	-0.18	0.19	0.02	0.22	0.34*	-0.34*	

TTNPH=Total tuber number per hill, LTSN= Large tuber size number, MTSN=medium tuber size number, STSN=small tuber size number, MTN=marketable tuber number, UMTN=unmarketable tuber number, TDM=tuber dry matter, MTY=marketable tuber yield, n=48, *, and ** indicates significant linear correlation at p<0.05 and p<0.01 respectively where as ns= no significant difference at p<0.05.