**International Journal of Animal Science and Technology**
2018; 2(4): 45-54
http://www.sciencepublishinggroup.com/j/ijast
doi: 10.11648/j.ijast.20180204.12
ISSN: 2640-1282 (Print); ISSN: 2640-1312 (Online)

# Response of Application Time and Method of Inorganic Phosphorus Fertilizer on Irish Potato (*Solanum tuberosum* L.) Production at Bore and Anasora Area, Southern Oromia, Ethiopia

**Solomon Teshome*, Tekile Bobo, Beriso Wako**

Oromia Agriculture Research Institute, Bore Agricultural Research Center, Bore, Ethiopia

**Email address:**
solomtesh41@gmail.com (S. Teshome), bobotekle@gmail.com (T. Bobo)

*Corresponding author

**To cite this article:**
Solomon Teshome, Tekile Bobo, Beriso Wako. Response of Application Time and Method of Inorganic Phosphorus Fertilizer on Irish Potato (*Solanum tuberosum* L.) Production at Bore and Anasora Area, Southern Oromia, Ethiopia. *International Journal of Animal Science and Technology*. Vol. 2, No. 4, 2018, pp. 45-54. doi: 10.11648/j.ijast.20180204.12

**Received**: November 14, 2018; **Accepted**: December 5, 2018; **Published**: January 7, 2019

**Abstract:** Optimizing fertilization brings tangible benefits such as higher yields and lower fertilizer costs, but also assures the sustainability of agricultural businesses. Appropriate nutrient application at critical time is often a crucial and increase rapidly during the tuber bulking phase and then slow as the plant matures. In recent years, however, some producers have applied some or all of the fertilizer in a concentrated and in inefficient form at a time carelessly. There is a limiting knowledge regarding time and appropriate method of application. The field trials were conducted during 2016 and 2017 main cropping season at the Bore Agricultural Research Centre on site and Ana sora on farm which is located in Guji Zone of Southern Ethiopia to evaluate the best P application time and method. The treatments consisted of Five (5) levels of application time (pre-planting (10DBP), at planting, at first weeding, at first earthingup and second earthingup stage (45DAP) and three (3) levels of application methods (band placement (localized placement or spot application), side dressing and broadcasting) will be arranged in RCBD with factorial arrangement of three replications. Sprouted tubers was planted on plot size of 2.1mx 3.5m and spacing of 30cm between plants and 70 cm between rows. The plot consists of five rows and seven plants per single row, totally 35 plants per plot. A distance of 0.6m and 1.4m was left between plots and blocks, respectively. Data were collected on growth, yield, yield components and disease incidence and severity. The two years combined data analysis results revealed that the interaction effect of fungicides and potato varieties had influenced significantly ($P<0.05$) response on days to 50% flowering, 50% maturity, plant height, number of tubers per hill, stem number per plant, marketable tuber yield and unmarketable tuber yield and total tuber yield. The highest economic yield (50.2 t $ha^{-1}$ and 49.98 t $ha^{-1}$) was obtained from the combined use of phosphorus at planting with banding. Generally, as a conclusive and recommendation, Irish potato growers at Bore, Ana sora and surrounding area need to grow Irish potato by applying phosphorus fertilizer at time of planting with banding method of application thereby phosphorus recovery can be improved for better use of plants.

**Keywords:** Days Before Planting, Days After Planting, Method, RCBD, Phosphorus, Potato, Time

## 1. Introduction

Agriculture is currently struggling with the challenge to increase food production by 70–100% in order to meet the food needs of a rising global population expected to reach over 9 billion people by 2050 [4, 9]. Options to raise food production include improving output from the current croplands, expanding existing croplands or simultaneously implementing both approaches and by adjusting the nutrient management with its efficient use of nutrients [15, 26].

Potatoes require optimal levels of essential nutrients throughout the growing season. Appropriate nutrient application at critical time is often a crucial and increase rapidly during the tuber bulking phase and then slow as the

plant matures. Low fertilizer use and imbalanced nutrient application are partially responsible for low tuber yields and quality throughout. Potatoes managed for maximum productivity have a high demand on soil nutrients. Potatoes grown are valued for yield, size, and also for dry matter content. Management factors, including fertility decisions, time of nutrient application and method of application will influence potato yield and quality [10].

In recent years, however, some producers have applied some or all of the fertilizer in a concentrated and in inefficient form. Placement of the fertilizer in a band may improve the efficiency of nutrient uptake from cold soils, because both ammonium and nitrate absorption by potato plant is reduced as soil temperatures decrease. When fertilizer (particularly phosphorus) comes in contact with soil it can be tied-up, reducing its availability to the plant. Band placement of fertilizer minimizes soil contact, reduces nutrient tie-up, and often results in increased fertilizer use efficiency.

Phosphorus is an essential plant nutrient required for optimum crop production. P is the second most limiting soil nutrient in crop production. Plants need phosphorus for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division. There are a number of methods of applying P fertilizer placement; however, some methods are more efficient than others. To obtain good P fertilizer efficiency, adequate rates of nitrogen and other nutrients must be available to the crop. Phosphorus fertilizer is immobile in soil; therefore, plant uptake of fertilizer P may be low in the first year after application. For optimum crop production, an adequate supply of P with appropriate method and time of application is ideal. Pre-plant banding of P with nitrogen has been found to be a good alternative method of application under certain conditions.

The placement of nutrients is an important issue in nutrient management because placement strongly influences the subsequent availability of nutrients. Improper placement can reduce yield and result economic loss. The right source of nutrients should be applied at the right rate during the right time and supplied to the right place to ensure their uptake. When nutrients are applied at a time when they are not required by the plant, the result can be economic and environmental losses. Placement can potentially affect water quality by altering nutrient leaching and runoff losses. For example, runoff losses of ammonium and phosphate were significantly less when MAP plus NH4NO3 fertilizer were injected at a 2 in. depth rather than broadcast [3].

An effective nutrient fertilization program coordinates amount timing and method of fertilizer application with plant demand and soil nutrient supply. Poor nutrient fertility management can lead to inefficient utilization, which can reduce crop yield (total yield), tuber quality, and pose significant environmental risk. Nitrogen is required in large amounts to maintain optimum shoot and tuber growth. The amount of nutrients available to meet a crop's requirement depends upon the efficiency of the management system. Any effort in crop production is achieved through increasing productivity rather than expansion of production area by combination of proper use of improved seeds and agricultural techniques including land preparation, proper fertilizers application methods and time and use of proper inputs and reducing crop losses due to pest and diseases.

Nutrient application should be made on the basis of plant demand. Plant demand is a function of growth rate, growth stage climatic conditions, and cultivar. The amount of nutrients required by a potato crop is also related to a realistic yield potential for the selected cultivar and land farmed. Thus, the amount of fertilizer applied to a potato crop should depend on the supplying power of the soil, the potential for nutrient loss, and the growth potential of the cultivar [8]. The application of essential plant nutrients in optimum quantity and right proportion, through correct method and time of application is the key to increased and sustained crop production [5]. The time at which P should be applied to a crop is very important because timing affects P efficiency and crop yield. Phosphatic fertilizers should not be applied much in advance of crop sowing since soluble P converts to less available form in the soil and its effectiveness declines with the time between application and the stage at which the crop is in a position to make use of nutrients [20, 23].

O'Brien *et al.* reported that P fertilizers should be top dressed with first irrigation rather than applied and incorporated in the soil at sowing time [21]. Another study reported that application of Phosphorus at planting was more effective than late application and the relative availability of P diminishes as the time between application and planting increases. Fixation of P increases as the time of contact between soluble P and soil particles increases. Consequently, more efficient utilization of fertilizer P is generally obtained by applying P fertilizer shortly before planting the crop [12].

The potential of horticultural crops in Guji Zone is not exploited due to lack of poor management practices, lack of improved farming method and high and long duration of rainfall. As stated above, absence of improved poor management practices are the main production problems of the area. Because of those constraints information on time of nutrient application and method of application are extremely important. Therefore, there is a need to determine the most effective methods and time of inorganic Phosphorus fertilizer application, and to establish recommendations concerning appropriate method and time of nutrient application on Irish potato production at Bore and Anasora.

# 2. Material and Methods

### *2.1. Description of the Study Sites*

The experiment was carried out during the 2016 and 2017 main cropping season at Bore Agricultural Research Center, Guji Zone of Southern Ethiopia. The first experimental site were located at Bore research site at the distance of about 8 km north of the town of Bore in Songo Bericha peasant association just on the side of the main road to Addis Ababa via Awassa town. Geographically, the experimental site is

situated at the latitude of 06°23'55''N and longitude of 38°35'5''E at an altitude of 2728 m above sea level. The second experimental site were located at Anasora district on farm at the distance of about 25 km East of the town of Anasora in Yirba Buliyo peasant association just on the side of the main road to Negele borana town. Geographically, the experimental site was situated at an altitude of 2600 m above sea level.

The climatic condition of the area is a humid moisture condition, with a relatively longer growing season. According to climate data from National Meteorological Agency, Awassa Branch Directorate (2015-2017), the area receives total average annual rainfall of 1640.5 mm with a bimodal pattern that extends from April to November. The mean annual minimum and maximum temperatures are 8.58°C and 18.6°C, respectively.

During the crop growing season the total amount of rainfall received were around 1105.9 and 981.2mm out of which 300.4 and 289.6mm were received in April and May followed by 281.7 and 219.2mm in May and June respectively. The Average maximum and minimum temperatures of the growing season were 21 and 9.6°C, respectively.

### *2.2. Treatments and Experimental Design*

Potato variety Belete was used as a test crop to evaluate its response to application time and method of P application. Five levels of application time (pre-planting (10DBP), at planting, at first weeding, at first earthingup and second earthingup stage (45DAP) and three levels of application methods (band placement (localized placement or spot application), side dressing and broadcasting) was arranged in RCBD with factorial arrangement of three replications. Recommended N/P rate of ((82 kg N and 92 kg P $ha^{-1}$) (100kg urea +200 kg DAP)) for Bore area was used for comparison. Sprouted tubers was planted on plot size of 2.1mx 3.5m and spacing of 30cm between plants and 70 cm between rows. The plot consists of five rows and seven plants per single row, totally 35 plants per plot. A distance of 0.6m and 1.4m was left between plots and blocks, respectively. Urea and DAP was used as sources of N and P. The doses of nitrogen were applied in equal split doses at planting and at reproduction stage (many ear leafs were easily visible upon dissection).

### *2.3. Soil Sampling and Analysis*

Initially soil sample (0-30cm) was taken before planting from 5-10 random locations across the plot with an auger. The soil samples was collected and air-dried and sent to Horticoop Ethiopia soil and water analysis laboratory for analysis of soil texture by hydrometer, total nitrogen following Kjedahl procedure, soil pH measured potentiometrically in water and 1M KCL solution at the ratio of 1:2.5 for both soil water and soil KCL solutions using a combined glass electrode pH meter (Chopra and Kanwar, 1976) and pH will be determined by subtracting soil pH (KCL) from soil pH ($H_2O$) method for soil. Organic carbon was also determined using wet digestion method and available phosphorus using Olsen II method [22, 38]. After harvest the crop, the soil samples was also taken from 0-30cm soils depth for each replications and composited treatment wise and analyzed for desired soil variable.

### *2.4. Crop Data Collection and Statistical Analysis*

Days to 50% emergency, flowering, maturity, plant height, stem number, average tuber weight, average tuber number per plant, marketable and unmarketable yield and total yield of the plant per plot was measured and converted to hectares.

The collected data on various parameters of the crop under study was statistically analyzed using SAS statistical package version 9.1.3 using Fishers protected LSD. The Least Significant Difference (LSD) test at 5% level of significance was used to separate the means when the ANOVA showed the presence of significant difference results [35].

## 3. Results and Discussions

A field experiment was carried out during 2016 and 2017 cropping season to determine the most effective methods and time of inorganic P fertilizer application, and to establish recommendations concerning appropriate method and time of nutrient application on Irish potato on Nitosols of Bore and Ana sora area, Guji zone. Most of the data collected from the field and laboratory analysis were subjected to statistical analysis and the results obtained are presented and discussed in the following sections.

### *3.1. Selected Physical and Chemical Properties of the Soil at Experimental Site*

Pre-plant soil (0-30 cm) analysis of the composite soil sample taken before planting at Bore and Anasora district demonstrated that the textural class of experimental soil belongs clay sandy loam soil texture (27% sand, 25% silt and 46% clay). The pH of the soil was strongly acidic (4.91 and 4.99) for both Bore and Anasora locations, respectively (Table 1). The total nitrogen of experimental soil was very high (0.33% and 0.34 %), having medium available P ratings (9.12 and 8.61 ppm) and medium (149 and 147.42 ppm) available potassium which have very high (5.73 and 6.12%) organic matter and high (29.90 and 30.90 meq/100g) rating of cation exchange capacity at Bore and Ana sora locations respectively (Table 1).

***Table 1.*** *Selected physical and chemical properties of experimental soil (0-30 cm) before planting.*

| Soil characters | Values | |
|---|---|---|
| | Bore | Ana sora |
| pH | 4.91 | 4.99 |
| Total nitrogen (%) | 0.33 | 0.34 |
| Organic carbon (%) | 3.32 | 3.55 |
| Available P (mg/l (pp)) | 9.12 | 8.61 |
| CEC (meq/100g) | 29.90 | 30.90 |
| Available K (mg/l (ppm)) | 149 | 147.42 |
| Organic matter (%) | 5.72 | 6.12 |

| Soil characters | Values | |
|---|---|---|
| | Bore | Ana sora |
| Soil texture: | | |
| Sand (%) | 27 | 27 |
| Silt (%) | 25 | 25 |
| Clay (%) | 46 | 48 |
| Class | Clay sandy loam | |

### *3.2. Phenological and Growth Parameters of Irish Potato*

Our combined Anova analysis indicated that the main effects of time of application and different application method as well as their interaction had significant ($P<0.05$) influence on days to 50% emergency, days to 50% flowering, days to physiological maturity, plant height and number of branches in all consecutive two years (Table 2). From the ANOVA analysis the result showed that the shortest days to emergency (14.33days) was attained in broadcasting method and ten days before planting application time where the longest (25.33 days) duration was observed in the all method of application with at time of first earthing-up and forty five days after planting on both Bore and Anasora locations for two years (Table 2). Some literature show that split P applications can improve P recovery by 25%, particularly on soils with low P content and low buffering capacity, and can improve physiological P use efficiency (PPUE) where P availability is limiting crop yield.

In conformity with the results obtained from this study, Cook R. J and RJ Veseth also found that effect of P placement method on days to emergence showed significant result [7]. Similarly, some authors reported that application of fertilizer near the seeds at the time of planting has the added advantage of stimulating seed germination and seedling emergence [28]. . Generally our result reviled that different placement method and application time of phosphorus fertilizer is done for efficient use of plant nutrients from plant emergence to maturity showed significant different among treatments by avoiding fixation of phosphate and convenient to the grower.

***Table 2.*** *Combined mean analysis of days to emergency, flowering, maturity, plant height and stem number of Irish potato crop at Bore and Ana sora sites during 2016 and 2017 cropping season.*

| Treatments | Phenology and Growth Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bore | | | | | Ana sora | | | | |
| | DE (days) | DF (days) | DM (days) | PH (cm) | STM (No) | DE (days) | DF (days) | DM (days) | PH (cm) | STM (No) |
| BC*10DBP | 15.00$^{de}$ | 77.00$^{ab}$ | 126.00$^{cd}$ | 85.66$^{a}$ | 5.66$^{abc}$ | 18.00$^{a}$ | 81.00$^{ab}$ | 130.33$^{cd}$ | 80.66$^{a}$ | 5.33$^{abc}$ |
| BC*PLT | 17.33$^{c}$ | 76.66$^{ab}$ | 117.00$^{f}$ | 80.66 $^{a}$ | 7.33$^{abc}$ | 18.00$^{c}$ | 80.33$^{abc}$ | 124.00$^{ef}$ | 76.66$^{a}$ | 6.33$^{ab}$ |
| BC*FWD | 20.66$^{b}$ | 78.66$^{a}$ | 122.33$^{de}$ | 59.33$^{b}$ | 4.66$^{c}$ | 22.33$^{b}$ | 83.00$^{a}$ | 127.00$^{de}$ | 56.00b | 3.66$^{c}$ |
| BC*FERTH | 25.00$^{a}$ | 73.00$^{abcd}$ | 129.33$^{bc}$ | 57.33 $^{b}$ | 4.33$^{c}$ | 25.66$^{a}$ | 76.66$^{abcd}$ | 132.66$^{bc}$ | 53.00$^{b}$ | 3.66$^{c}$ |
| BC*45DAP | 25.33$^{a}$ | 76.66$^{ab}$ | 136.00$^{a}$ | 57.33 $^{b}$ | 4.66$^{c}$ | 25.66$^{a}$ | 79.66$^{abc}$ | 140.66$^{a}$ | 59.33$^{b}$ | 3.33$^{c}$ |
| SDR*10DBP | 15.00$^{de}$ | 67.00$^{e}$ | 116.66$^{f}$ | 85.33 $^{a}$ | 6.33$^{abc}$ | 17.33$^{c}$ | 74.00$^{bcd}$ | 121.66$^{f}$ | 78.00$^{a}$ | 5.33$^{abc}$ |
| SDR*PLT | 16.66$^{cd}$ | 69.33$^{de}$ | 117.00$^{f}$ | 86.66 $^{a}$ | 7.33$^{abc}$ | 18.66$^{c}$ | 72.00$^{d}$ | 124.33$^{ef}$ | 80.66$^{a}$ | 6.33$^{ab}$ |
| SDR*FWD | 21.66$^{b}$ | 73.00$^{abcd}$ | 125.66$^{cd}$ | 59.66 $^{b}$ | 5.33$^{bc}$ | 24.33$^{ab}$ | 76.33$^{abcd}$ | 131.33$^{cd}$ | 55.00$^{b}$ | 4.33$^{bc}$ |
| SDR*FERTH | 24.66$^{a}$ | 75.33$^{abc}$ | 128.66$^{bc}$ | 57.00 $^{b}$ | 5.33$^{bc}$ | 25.00$^{a}$ | 81.33$^{a}$ | 132.33$^{bc}$ | 53.66$^{b}$ | 4.66$^{abc}$ |
| SDR*45DAP | 25.00$^{a}$ | 76.00$^{ab}$ | 131.66$^{ab}$ | 56.66 $^{b}$ | 6.66$^{abc}$ | 25.66$^{a}$ | 79.33$^{abc}$ | 136.00$^{b}$ | 50.33$^{b}$ | 6.33$^{abc}$ |
| BND*10DBP | 14.33$^{e}$ | 67.00$^{e}$ | 120.66$^{ef}$ | 80.33 $^{a}$ | 8.66$^{a}$ | 17.00$^{c}$ | 71.00$^{e}$ | 125.33$^{ef}$ | 74.66$^{a}$ | 7.33$^{a}$ |
| BND*PLT | 16.33$^{cd}$ | 70.00$^{cde}$ | 125.33$^{cd}$ | 84.33 $^{a}$ | 8.00$^{ab}$ | 19.00$^{c}$ | 74.00$^{bcd}$ | 130.00$^{cd}$ | 79.33$^{a}$ | 7.00$^{a}$ |
| BND*FWD | 20.33$^{b}$ | 68.80$^{de}$ | 126.33$^{cd}$ | 61.66 $^{b}$ | 6.00$^{abc}$ | 22.33$^{b}$ | 72.00$^{d}$ | 130.66$^{cd}$ | 56.66$^{b}$ | 5.00$^{abc}$ |
| BND*FERTH | 25.00$^{a}$ | 76.33$^{ab}$ | 129.33$^{bc}$ | 61.00 $^{b}$ | 6.00$^{abc}$ | 25.00$^{a}$ | 79.66$^{abc}$ | 132.33$^{bc}$ | 55.66$^{b}$ | 5.00$^{abc}$ |
| BND*45DAP | 25.33$^{a}$ | 71.33$^{bcde}$ | 126.66$^{cd}$ | 53.66 $^{b}$ | 6.00$^{abc}$ | 26.66$^{a}$ | 73.33$^{cd}$ | 132.00$^{bc}$ | 50.66$^{b}$ | 5.00$^{abc}$ |
| Mean | 20.51 | 73.68 | 125.24 | 68.44 | 6.132 | 22.04 | 77.57 | 130.04 | 64.02 | 5.31 |
| LSD (5%) | 1.79$^{**}$ | 5.74$^{**}$ | 4.63$^{**}$ | 8.95$^{**}$ | 3.22$^{**}$ | 2.54$^{**}$ | 7.00$^{**}$ | 4.52$^{**}$ | 11.59$^{**}$ | 2.90$^{**}$ |
| CV (%) | 5.24 | 4.67 | 2.21 | 7.84 | 31.50 | 6.92 | 5.41 | 2.08 | 10.86 | 32.85 |

Means in columns and rows followed by the same letter (s) are not significantly different at 5% level of significance. 10DBP=ten days before planting, PLT=at planting, FWD=at first weeding, FERTH= at first earthingup, 45DAP= forty five days after planting, DE= days to emergency, DF= days to flowering, DM=days to maturity, PH=plant height, STM=stem number, LSD (0.01) = Least Significant Difference at 5% level; and CV (%) = coefficient of variation in percent

And also our Anova result showed that the maximum (78.66 and 78.00) days to flowering recorded for treatments of broadcasting and banding method of phosphorus application with first weeding and the shortest (67.00 days) days to flowering was observed for treatment combination of side dress phosphorus application method with ten days before planting. This may be because of one is application of fertilizers hastens flowering day and the other could be phosphorus fertilizer is immobile in soil; therefore, plant uptake of fertilizer P may be low at application time efficiently and reduces nutrient tie-up and increased fertilizer use efficiency. The maximum (136) days to maturity was observed for interaction effect of treatment broadcasting and forty five days after planting. Moreover, the mean days to early (116, 117, 121 and 121.66) maturity was recorded by the interaction effect of side dress and banding method of P application with 10 DBP and P application at time of planting.

Similarly the combined mean analysis indicated that both the main and interaction effect of time and method of phosphorus application significantly ($P<0.05$) influenced plant height and stem number of the plant (Table 2). The

highest (85.66, 85.33, 86.66, 84.33, 80.66 and 80.33 cm) plant height was recorded on broadcasting, side dress and banding fertilizer application method with ten days before planting and at planting time (Figure 1).

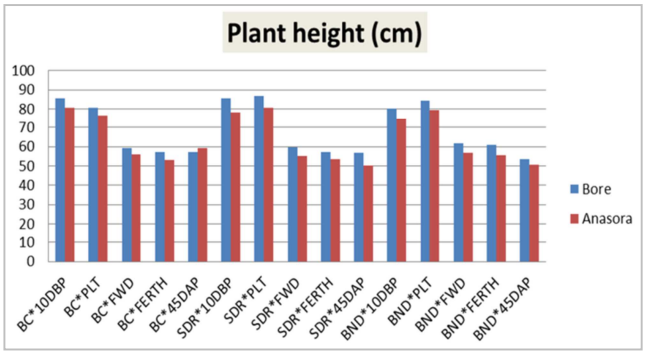


***Figure 1.*** *Interaction effect of time and method of phosphorus application on plant height at Bore and A/sora locations.*

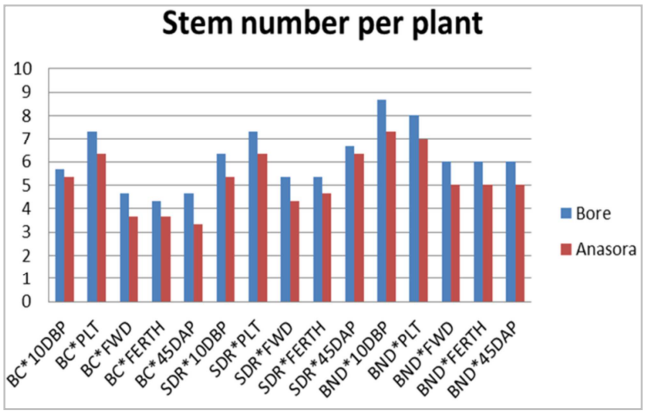


***Figure 2.*** *Interaction effect of time and method of phosphorus application on stem number at Bore and A/sora locations.*

The increasing of plant height may be due to the role of such macro nutrient in the physiological process and cell division and elongation which indirectly effect tissue formation and consequently vegetative growth of plant. Here early application of phosphorus can therefore impact crop growth and soil fertility since retained by soils. Basically the efficiency of an application was evaluated for two seasons. But for proper evaluations of residual effects require longer time to truly get their full impacts [36]. Dubois (2011) reviewed the effect of P in potato and concluded that both height and leaf area index are positively related to P fertilizer application in P deficient soils. Similarly Spreading fertilizer and seed in a wide band can minimize germination problems due to less direct contact between fertilizer and seed [11].

The maximum (8.66, 8, 7.33 and 7) stem number of Irish potato was obtained by interaction effect of treatment banding with ten days before planting and at time of planting (Figure 2). The adverse effect on stem number per plant was more pronounced in treatment BND application method with 10DBP and at planting application time may likely be the better treatment for nutrient use efficiencies than other treatments. A goal of fertilizer placement is to maximize root-nutrient contact, especially at the critical stages of crop development, without causing emergence problems. This may be due to that placing the Phosphorus in the right method at the right time may produce highest density of fine roots that conversely develop highest stem number. This parameter is of great importance because it is directly related with the total production of tubers. The more is the number of stems/plant the more will be the number of tubers per plant.

In many states in the western U.S. Corn Belt, recommendations exist for reducing fertilizer rates if they are applied in a band, rather than broadcast [22, 31]. Often, banded and side dress rates are reduced to half of the broadcast rate.

### *3.3. Yield Related and Yield Parameters of Irish Potato*

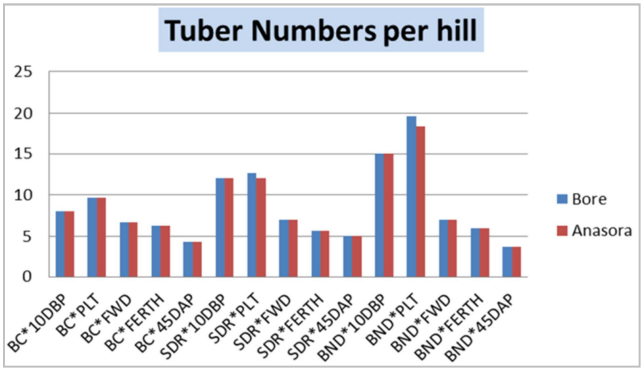


***Figure 3.*** *Interaction effect of time and method of phosphorus application on tubers per hill at Bore and A/sora locations.*

The main effects of application time and method as well as their interaction had significant ($P<0.05$) influence on Irish potato tuber number per hill and average tuber weight in all locations and years (Table 3). The maximum number of tubers per hill (19.66 and 18.33) was observed when tubers were planted and phosphorus was applied at time of planting and banding at Bore and Ana sora, respectively. And also the second most maximum (15) tuber number per plant was recorded when P was applied at time of 10 DBP with banding method of application on both Bore and Ana sora locations. Min while the minimum (3.66) number of tubers per hill was recorded when phosphorus was applied in band and broadcasting application method with forty five days after planting time of application at Bore and Ana sora locations, respectively (figure 3). This may be due to the fact that contact of phosphorus at appropriate time with method to the soil has good impact on crop quality include increasing the number of tuber per plant. Agricultural land often contains significant amounts of Phosphorus. But most of this P is bound in different complexes in the soil [24]. Therefore, phosphorus fertilizer needs to be added continuously to sustain optimal plant growth. Potato is considered a P-demanding crop due to its shallow and relatively short root system [13]. Fertilizer P recommendations for potato are therefore higher than for most other crops [1, 2]. Optimum application time enhanced release of nutrients from the soil promoted root growth and nutrient uptake, hence better root

growth and yield that enhances better tuber setting.

The analysis of variance shows that the main effects of application time and application method as well as their interaction had highly significant response on tuber weight of Irish potato in both consecutive two years at both Bore and Ana sora districts (Table 3). When fertilizers are placed at the right place then there will be minimum contact between the soil and fixation of nutrients is greatly reduced. And thus leads to residual response of fertilizers are usually higher. Then the utilization of the fertilizer of the plant will be higher. Being immobile, phosphates are better utilized when placed.

The maximum (272.1 gm and 238.83 gm) tuber weight was recorded by banding application method of phosphorus at planting and followed (239.3 gm and 226.03 gm) by banding method of phosphorus application at ten days before planting application time. Conversely the minimum (71.5 gm, 79.66 gm, 89.93 gm, 99.83 gm, 100.9 gm and 104.8 gm) was recorded for treatments treated with all application methods with application time at first earthing up and 45DAP on both locations (figure 4).

Even though there is lack of researches on application time of phosphorus fertilizers our research work showed that application of Phosphorus at planting and ten days before planting gives better result on number of tubers and tuber weight of Irish potato. The results of five years' experimental work comparing different methods of fertilizer placement for the potato crop showed conclusively that in the great majority of tests conducted, placement of fertilizer in band application gave best returns.

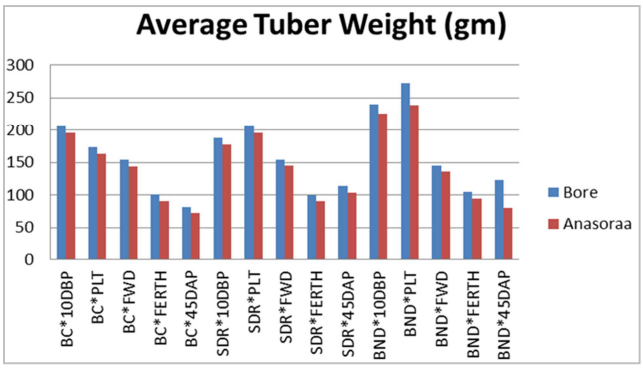


***Figure 4.*** *Interaction effect of time and method of phosphorus application on tubers per hill at Bore and A/sora locations.*

Furthermore, Hussain and Haq (2000) explained that optimum phosphorus application time mostly enhances early crop development and that the response to P application decreases with time. This implies phosphorus is taken up by the potato crop continuously over the growing season. However, the amount taken up per day varies depending on the phenological stage [16]. Although P is crucial, the element is needed in relatively small amounts, 0.5 kg $ton^{-1}$ compared with 3 kg $ton^{-1}$ for N and 4 kg $ton^{-1}$ for K [3, 7, 30, 31]. The highest P uptake rate in foliage and tubers occur during the tuber formation and tuber development stage [6].

***Table 3.*** *Combined mean analysis of tuber number, tuber weight, and marketable, unmarketable and total yield of Irish potato crop at Bore and Ana sora sites during 2016 and 2017 cropping season*

| Treatments | Yield and yield related Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bore | | | | | Ana sora | | | | |
| | TNP (No) | ATW (gm) | MY (kut $ha^{-1}$) | UMY (kut $ha^{-1}$) | TY (kut $ha^{-1}$) | TNP (No) | ATW (gm) | MY (kut $ha^{-1}$) | UMY (kut $ha^{-1}$) | TY (kut $ha^{-1}$) |
| BC*10DBP | $8.00^{ef}$ | $206.6^{bc}$ | $401^{bcd}$ | 63 | $465^{abc}$ | $8.00^{de}$ | $196.00^{bc}$ | $394.47^{cd}$ | $60.54^{bc}$ | $455.01^{bcd}$ |
| BC*PLT | $9.66^{de}$ | $173.3^{cd}$ | $385^{cd}$ | 44 | $429^{abcd}$ | $9.66^{cd}$ | $163.33^{cde}$ | $418.36a^{bc}$ | $19.51^{g}$ | $437.88^{cd}$ |
| BC*FWD | $6.66^{fgh}$ | $153.5^{de}$ | $365^{de}$ | 45 | $410b^{cde}$ | $6.66^{efg}$ | $143.53^{def}$ | $361.89^{de}$ | $28.39^{fg}$ | $390.28^{efg}$ |
| BC*FERTH | $6.33^{fgh}$ | $100.9^{fg}$ | $310^{f}$ | 53 | $363^{f}$ | $6.33^{efg}$ | $90.93^{h}$ | $313.54^{f}$ | $46.37^{cdef}$ | $359.90^{g}$ |
| BC*45DAP | $4.33^{hi}$ | $81.50^{g}$ | $300^{f}$ | 71 | $372^{f}$ | $4.33^{gh}$ | $71.50^{h}$ | $206.75^{h}$ | $50.78^{cd}$ | $257.52^{h}$ |
| SDR*10DBP | $12.0^{cd}$ | $187.8^{cd}$ | $422^{abc}$ | 68 | $474^{ab}$ | $12.00^{c}$ | $177.80^{cd}$ | $420.00^{abc}$ | $31.29^{efg}$ | $451.30^{bcd}$ |
| SDR*PLT | $12.6^{bc}$ | $206.1^{bc}$ | $424^{abc}$ | 35 | $460^{abcd}$ | $12.00^{c}$ | $195.46^{bc}$ | $412.19^{bc}$ | $15.65^{g}$ | $427.84^{de}$ |
| SDR*FWD | $7.00^{fg}$ | $154.3^{de}$ | $382^{cd}$ | 70 | $452^{abcd}$ | $7.00^{ef}$ | $144.30^{def}$ | $386.02^{cd}$ | $90.07^{a}$ | $476.09^{abc}$ |
| SDR*FERTH | $5.66^{fghi}$ | $99.83^{fg}$ | $328^{ef}$ | 54 | $382^{cdef}$ | $5.66^{efgh}$ | $89.83^{h}$ | $252.60^{g}$ | $44.12^{cdef}$ | $296.72^{h}$ |
| SDR*45DAP | $5.00^{ghi}$ | $113.3^{efg}$ | $316^{f}$ | 45 | $361^{f}$ | $5.00^{fgh}$ | $103.33^{fgh}$ | $217.92^{gh}$ | $48.73^{cde}$ | $266.65^{h}$ |
| BND*10DBP | $15.00^{b}$ | $239.3^{ab}$ | $439^{ab}$ | 50 | $490^{ab}$ | $15.00^{b}$ | $226.03^{ab}$ | $451.63^{ab}$ | $40.06^{def}$ | $491.70^{ab}$ |
| BND*PLT | $19.66^{a}$ | $272.1^{a}$ | $460^{a}$ | 42 | $502^{a}$ | $18.33^{a}$ | $238.83^{a}$ | $457.83^{a}$ | $42.02^{cdef}$ | $499.86^{a}$ |
| BND*FWD | $7.00^{fg}$ | $145.4^{def}$ | $386^{cd}$ | 69 | $456^{abcde}$ | $7.00^{ef}$ | $135.40^{efg}$ | $366.01^{de}$ | $46.28^{cdef}$ | $412.30^{def}$ |
| BND*FERTH | $6.00^{fghi}$ | $104.8^{fg}$ | $332^{ef}$ | 45 | $377^{def}$ | $6.00^{efg}$ | $94.83^{gh}$ | $330.09^{ef}$ | $41.67^{def}$ | $371.77^{fg}$ |
| BND*45DAP | $3.66^{i}$ | $123.0^{efg}$ | $291^{f}$ | 70 | $362^{f}$ | $3.66^{h}$ | $79.66^{h}$ | $201.96^{h}$ | $76.77^{ab}$ | $27873^{h}$ |
| Mean | 8.57 | 157.4 | 369 | 55 | 424 | 8.44 | 143.38 | 346.08 | 45.48 | 391.57 |
| LSD (5%) | 2.64 | 48.57 | 45.94 | Ns | 83.85 | 2.55 | 41.32 | 41.39 | 18.82 | 43.16 |
| CV (%) | 18.47 | 18.49 | 7.45 | 49.02 | 11.86 | 18.17 | 17.28 | 7.17 | 24.82 | 6.61 |

Means in columns and rows followed by the same letter (s) are not significantly different at 5% level of significance. 10DBP=ten days before planting, PLT=at planting, FWD=at first weeding, FERTH= at first earthingup, 45DAP= forty five days after planting, TNP= tuber number, ATW= tuber weight, MY=marketable, UMY=unmarketable and TY=total yield LSD (0.01) = Least Significant Difference at 5% level; and CV (%) = coefficient of variation in percent

The analysis of variance shows that the interaction effect of phosphorus application time and application method had

significant effects on marketable and total tuber yield of Irish potato in both consecutive two years at both locations (Table 3). But our study reveals there was no significant different between each treatment by application method and application time on unmarketable yield at Bore location but difference at Anasora site.

Our Anova analysis revealed that applying phosphorus in banding at planting time produced maximum (460 kut $ha^{-1}$ and 457.83 kut $ha^{-1}$) marketable yield at Bore and Ana sora locations, respectively. Here in this study applying phosphorus in banding method with applying ten days before planting give the second maximum (439 kut $ha^{-1}$ and 451.63 kut $ha^{-1}$) marketable tuber yield at Bore and Anasora locations, respectively. And the minimum (291 kut $ha^{-1}$, 300 kut $ha^{-1}$, 310 kut $ha^{-1}$, 316 kut $ha^{-1}$, 201.6 kut $ha^{-1}$ and 206.75 kut $ha^{-1}$) marketable yield was produced by broadcasting, side dressing and banding method of phosphorus application with first earthing up and 45 days after planting application time. Similarly the highest (502 and 499.86 kut $ha^{-1}$) total fresh tuber yield was obtained from banding application method with P application a time of planting at Bore and Ana sora locations, respectively. And the lowest (361 kut $ha^{-1}$, 362 kut $ha^{-1}$ and 372 kut $ha^{-1}$) was recorded by all type of phosphorus application method with applying phosphorus forty five days after planting at Bore and Ana sora location respectively.

Topdressing of P is not expected to affect crop yield because the P would likely become bound near the soil surface and not migrate to the actively growing root system. Therefore P should be applied immediately before or at planting due to its immobility in soil. Timing fertilization with peak nutrient uptake demand is essential for optimizing both yield and quality. In general, nutrient uptake rates are highest from early to mid-growing season, which is why fertilization near the time of seeding is generally very effective. The conventional wisdom was that applying P in broadcast results in much more fertilizer-soil contact, which precipitates or sorbs P, decreasing its availability. Instead, a study with 'radiolabelled' P found that P banding is more effective than broadcast P because it increases the chance that active roots will contact P, rather than due to decreased fertilizer-soil contact [33]. Banded P application method at planting and 10 DBP generally increases crop yields, as compared to broadcast P, especially on low and medium P testing soils. On soils with high levels of available P, the advantage of banding is less because the crop obtains a higher proportion of P from the soil rather than from added fertilizer.

Increase in tuber number per plant, tuber weight, marketable and total yield was noted in the plots that received Phosphorus at planting application time with banding method and followed by 10 DBS with band P application method indicate more P availability at higher P rates. Griffith (1983) suggested that soils of clay loam texture with high fixation capacity have higher demand for P fertilizer [14]. Rehm *et al* (2006) found that clay loam texture had maximum P fixation and to get proper amount of P availability, P-fertilizers should not be applied much before plantation to minimize P fixation [25]. Optimizing phosphorus fertilizer management on potato (*Solanum tuberosum* L.) crop is challenging. The "4R" nutrient stewardship framework of using fertilizer at the right rate, right source, right placement and right time provides approaches to improve fertilizer use efficiency while maintaining or improving yield. Fertilizer should be applied in bands on each side of the seed piece with two inches of fertilizer-free soil interposed. This finding is in line with Leikam *et al.* (1983) who suggest that tuber yield is positively correlated with light quantity absorbed by the crop during the first week of initiation [19]. Since P fertilization increases the interception of solar radiation in low soil P conditions, it is likely that P fertilization has a positive effect on tuber set in such conditions during early application [37].

A field experiment was conducted to investigate impact of P levels and time of P application [40, 30, 20 and 10 days before sowing (DBS), at sowing and 15 days after sowing (DAS)] at New Developmental Agricultural Research Farm of KPK Agricultural University Peshawar, during summer 2005. The results showed that the highest level of P $ha^{-1}$ at 10 DBS and sowing increased plant height, number of tubers per plant, tuber weight, stem number per plant and yield. In another way broadcasting is the least efficient method from a plant perspective, but the most widely used application method in practice. Precision placement of P fertilizer near the active root zone is the most commonly recommended application method. Placement of the fertilizer reduces the contact area with the soil, thus avoiding soil binding [18]. Placement may decrease the P sorption rate, affecting P acquisition positively. This can decrease the P fertilization requirement by approximately 50%. Therefore higher tuber yield can be obtained if the P fertilizer is placed 5 cm to the side of the seed pieces with banding instead of being placed below or mixed into the ridges by broadcasting [11].

### *3.4. Physio Chemical of the Soil After Crop Harvest*

Table 4 summarizes some of the post-harvest physio-chemical properties of soil as affected by different P application time and method treatments. Post-harvest analysis of soil revealed an increase in organic matter respective of phosphorus application methods and application time treatments. Under different phosphorus application methods and application time treatments the highest (6.65 %, .47 % and 6.36 %) degree of increases in organic matter was recorded in case of first earthing-uptime and side dress application method, 45 DAP with broadcasting application method and 45 days after potato planting and side dressing of phosphorus application treatments. However there was no significant ($p>0.05$) difference among the treatments of p application method and time. Most of the treatments respond in strongly acidic range.

***Table 4.*** *Selected physio-chemical properties of the topsoil (0-30 cm),) of experimental field at crop harvest for each treatments.*

| TRT (T*M) | pH | P | K | S | OC | N | C:N | CEC | Soil texture | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | sand | Silt | clay |
| FWD*BRD | 4.99 | 8.61 | 147.42 | 20 | 3.55 | 0.33 | 10.68 | 30.9 | 27 | 25 | 48 |
| FWD*BND | 5.00 | 8.79 | 147.14 | 16.5 | 3.49 | 0.34 | 10.26 | 30.5 | 25 | 27 | 48 |
| FERTH*SDR | 4.94 | 10.6 | 172.92 | 18 | 3.86 | 0.35 | 11.1 | 28.1 | 24 | 28 | 48 |
| 10DBP*SDR | 4.96 | 7.98 | 130.75 | 21 | 3.65 | 0.37 | 9.81 | 32.2 | 33 | 24 | 43 |
| 45DAP*BND | 4.94 | 10.76 | 162.75 | 1.0 | 3.58 | 0.34 | 10.59 | 29.2 | 31 | 23 | 46 |
| 10DAP*BND | 4.9 | 8.44 | 164.77 | 19.5 | 3.58 | 0.34 | 10.65 | 30.6 | 25 | 229 | 46 |
| FERT*BRD | 4.97 | 13.22 | 162.29 | 21 | 3.57 | 0.35 | 10.29 | 30.6 | 25 | 31 | 44 |
| PLT*SDR | 4.99 | 7.41 | 131.88 | 16.5 | 3.22 | 0.33 | 9.69 | 32.1 | 27 | 25 | 48 |
| PLT*BND | 5.07 | 6.92 | 146.86 | 22.5 | 3.45 | 0.34 | 10.21 | 30.8 | 27 | 27 | 46 |
| FERT*BND | 4.97 | 8.16 | 196.1 | 23 | 3.61 | 0.35 | 10.32 | 29.5 | 28 | 24 | 48 |
| FWD*SDR | 4.96 | 7.94 | 163.84 | 15 | 3.48 | 0.34 | 10.22 | 31.3 | 31 | 25 | 44 |
| 10DBP*BRD | 4.91 | 7.00 | 147.56 | 21 | 3.38 | 0.34 | 10.07 | 29.9 | 27 | 24 | 49 |
| 45DAP*BRD | 4.96 | 10.2 | 163.06 | 24 | 3.75 | 0.34 | 11.13 | 31.6 | 26 | 24 | 50 |
| PLT*BRD | 5.22 | 9.0 | 180.8 | 22.15 | 3.35 | 0.33 | 10.09 | 26.33 | 30 | 28 | 42 |
| 45DAP*SDR | 4.97 | 10.3 | 17.5 | 40.2 | 3.69 | 0.35 | 10.47 | 33.3 | 30 | 20 | 50 |

Regarding the total nitrogen content between each treatment didn't show difference. Most of the treatments show in high total nitrogen content in the soil even after crop harvest. Similarly, maximum (0.37 % and 0.35 %) increase in total N content were more perceptible in case of application of phosphorus ten days before planting with side dressing method and at first earthing up with broadcasting method treatments (Table 4). The effects of different methods of P placement method and, P application time and their interaction on total soil nitrogen were non-significantly ($P>0.05$) different. However, the overall effect of side dressing and banding P placement resulted in more (0.37 % and 0.35 %) soil N than both the remaining methods of Phosphorus placement. This indicated that side dressing and banding

Phosphorus to the side of the seed had generally apparent advantage on total soil nitrogen. There was also a tendency of increasing total soil nitrogen with increasing P rates.

The results of soil analysis for available soil P after harvest against treatments are presented in Table 10. There was highly significant difference in Olsen extractable available soil P across P application time and P placement methods and their combined effects with the application of P in the form of diammonium phosphate (Table 4). Side dressing and Banding of P fertilizer to the sides of the tuber at the time of planting and ten days before planting significantly ($P<0.05$) increased available P to 13.22 ppm, 10.76 ppm, 10.6 ppm, 10.32 ppm and 10.12 ppm over broadcasting, banding and side dressing of phosphorus. Among the above three methods of P placements, the highest (13.22 ppm) increment in soil available P was obtained by the use of broadcasting P to the tuber at time of first earthing-up and also the lowest (7 ppm) by using broadcasting P method of application at time of forty five days after planting.

Cation exchange capacity (CEC) and temperature also have influences on availability of nutrient. Cation exchange capacity implies amount of nutrient available to plants as exchangeable cations and the degree to which the exchangeable complex is saturated with bases rather than $H^+$. The maximum (33.3, 32.2, 32.1 and 31.6 cmol $kg^{-1}$) CEC of the study area was recorded from treatments of 10DBP and plating time with banding and side dress method of P application.

# 4. Summary and Conclusion

The environmental significance of P lies in its dominant role in the eutrophication of aquatic ecosystems, where P is regarded as the limiting nutrient for primary production. It has been argued recently that the soil P status should be kept close to the 'critical value'. The concept of critical value optimizes the economic returns for the farmer and reduces the risk of P losses to surface waters. Efficient use of P is crucial in order to minimize losses of P from agro-ecosystems [32]. Phosphorus fertilizer can be applied in several different ways to the potato crop. It can be banded, broadcast, side dressed or applied through fertigation or by foliar application. In most cases the fertilizer is spread prior to planting and then incorporated into the ridges by cultivation. However, when the fertilizer is mixed into the ground soil contact area increases, it results in a high adsorption rate [29].

The effective placement and timing of fertilizers can maximize both yield and nutrient use efficiency, thereby increasing net profit for the producer. A goal of fertilizer placement is to maximize root-nutrient contact, especially at the early stages of root development, without causing emergence problems. Placing fertilizer in the region that will have the highest density of fie roots, or in a location that the fertilizer will move to this region, is needed to optimize yield. Less soluble fertilizers, such as P, placed to the side of the seed will be accessed earlier in the growing season.

Unlike N, P is relatively immobile in the soil. Consequently, P placement is expected to cause larger effects on P availability and crop yield. For example banded pre-plant P application gives twice as much yields than when the same fertilizer was broadcast [17]. This advantage was partially attributed to a lack of active roots near soil demonstrating a strong economic advantage of banding P [27]. In order to increase nutrient use efficiency, native to the

soil or added through fertilizers, it is necessary to examine the many variables that interact with fertilizer application. Soil, crop, expected climatic conditions, cropping systems and general crop management are decisive factors that should be carefully studied to obtain not just the desired nutrient efficiency, but also the desired profit.

The study was proposed to determine the most effective methods and time of inorganic Phosphorus fertilizer application, and to establish recommendations concerning appropriate application method and time of phosphorus on Irish potato. Potato variety Belete was used as a test crop to evaluate its response to application time and method of P application. Five levels of application time (pre-planting (10DBP), at planting, at first weeding, at first earthingup and second earthingup stage (45DAP) and three levels of application methods (band placement (localized placement or spot application), side dressing and broadcasting) were arranged in RCBD with factorial arrangement of three replications on a clay loam soil during the year of 2016-2017. Sprouted tubers was planted on plot size of 2.1mx 3.5m and spacing of 30cm between plants and 70 cm between rows. The plot consisted of five rows and seven plants per single row, totally 35 plants per plot were employed. A distance of 0.6m and 1.4m was left between plots and blocks, respectively.

Therefore the results revealed that the interaction effect between application time and method had highly significant ($P<0.05$) responded on days to 50% emergency, 80% maturity, plant height, number of tubers per hill, stem number per plant, marketable tuber yield and total tuber yield. On the other hand our Anova result shows non-significant ($P<0.05$) effect by the application time and method on unmarketable tuber yield.

Our recommendation to phosphorus application time and method provide a new opportunity to manipulate application time and method of fertilizer to maximize use of appropriate time and nutrient resources. Using phosphorus fertilizer at planting with banding has significantly ($P<0.05$) and positively increased the total tuber yield of Irish potato at Bore and Anasora area. The highest economic yield (50.2 t $ha^{-1}$and 49.98 t $ha^{-1}$) was obtained from the combined use of phosphorus at planting with banding followed by second highest (49.0 t $ha^{-1}$ and 49.17 t $ha^{-1}$) total tuber yield was obtained by combined application of P 10DBP and with banding at Bore and Anasora districts, respectively. In order to obtain high nutrient use efficiency farmers are advised to carefully consider the principles of the 4R nutrient stewardship concept. Recently IFA and IPNI have been emphasizing the use of the 4R nutrient stewardship concept as a general guideline for good practices related to nutrient use. It primarily considers that nutrients have to be applied at the right source, right rate, right time and right place. Therefore it can be concluded that different phosphorus application method and application time have remarkable effect on growth and development of Irish potato. Generally, as a conclusive and recommendation, Irish potato growers at Bore, Anasora and surrounding area need to grow Irish potato by applying phosphorus fertilizer at time of planting with banding method of application thereby PUE and phosphorus recovery can be improved if phosphorus fertilizers are applied.

Generally Fertilizer placement and timing can have substantial effects on both crop yield and quality. Placement techniques include broadcast, banded (surface or subsurface) and side dress placement. The likelihood of a placement response for a particular nutrient is related to both the mobility of that nutrient and on water availability. For example, yield responses from placement of N, which is highly mobile, are less than for P and metal micronutrients, which are relatively immobile. Timing of fertilizer application can also affect both yield and quality. Applying near the time of planting generally will produce high levels of nutrients in time for peak growth demand that occurs from early-mid growing season. Generally, as a conclusive and recommendation, Irish potato growers at Bore, Anasora and surrounding area need to grow Irish potato by applying phosphorus fertilizer at a time of planting with banding method of application to increase their production.

## Acknowledgements

I express my sincere gratitude to Oromia Agricultural Research Institute for granting fund for this research. I also want to extend my appreciation and special thanks to Bore Agricultural Research Center for they were helping me from the very beginning of the research proposal initiation to research conducting by different resources. Furthermore, I would greatly acknowledge all Horticulture and Spice Team members for their valuable effort during research work.

## References

[1] Albertsson, B. (2012). Riktlinjer för gödsling och kalkning 2013. Jönköping 90 pp.

[2] Allison, M. F., Fowler, J. H. and E. J Allen (2001). Effects of soil and foliar applied phosphorus fertilizers on the potato (*Solanum tuberosum L.*) crop. Journal of Agricultural Science. 137: 379-395.

[3] Baker, J. L. and J. M. Lafln (1982). Effects of corn residue and fertilizer management on soluble nutrient runoff loss. Trans. ASAE. 25:344-348.

[4] Bennett W. F (1993). Nutrient deficiencies and toxicities in crop plants: American Phytopathological Society., 202 p.

[5] Bruinsma J (2009). *The resource outlook to 2050*. In: Expert Meeting on "How to Feed the World in 2050", 24–26 June 2009, FAO, Rome, Italy.

[6] Cisse, L. and B. Amar (2000). *The importance of Phosphatic fertilizer for increased crop production in developing countries*. In: *Proceedings of the AFA 6th International Annual conference.*

[7] Cook R. J and RJ Veseth (1991). Wheat Health Management. The American Phytopathological Society, pp: 152, USA.

[8] Covarrubias-Ramírez, J., Castillo-Aguilar, S., Vera-Núñez, J., Núñez-Escobar, R., Sánchez-García, P., Aveldaño-Salazar, R. and J Peña-Cabriales (2005). Phosphorus uptake and use efficiency by potato cultivar Alpha using 32P. Agrociencia 39 (2): 127-136.

[9] Dampney, P., Johnson, P., Goodlass, G., Dyer, C. and AS Sac (2002). Review of the response of potatoes to phosphate. DEFRA project PE0108, 52.

[10] Dean BB (1994). Cultivation, fertilization, and irrigation. In: Managing the potato production system. Haworth Press, Inc. New York. Pp: 69–83.

[11] Dubois O (2011). The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk. FAO, Rome, Italy.

[12] Gerwing, J. and R. Gelderman (2005). South Dakota fertilizer recommendations guide. Sep. 2005. EC750. South Dakota Coop. Ext. Serv., South Dakota State Univ., Brookings. Available online at http://agbiopubs.sdstate.edu/articles/ EC750.pdf (verified 14 Aug. 2009).

[13] Grewal, J. S., Trehan, S. P. and, RC Sharma (1993). Phosphorus and potassium nutrition of potato. Advances in Horticulture 7:262–97.

[14] Griffith B (1983). Efficient uses of phosphorus fertilizer in irrigated land. *Soil Science J*ournal, 148: 7-9.

[15] Harris PM (1992). Potato crop: The Scientific Basis for Improvement. Chapman and Hall (Vol 2). 730 pp.

[16] Hussain, M. Z. and IU Haq (2000). *P sorption capacities of KPK soils*. In: *Proceedings of symposium on integrated plant nutrient management held at Islamabad* on 8-10 November 1999. Pp: 284-296.

[17] IPCC (2007). Climate Change 2007. Cambridge University Press, New York, NY.

[18] Jenkins, P. and H Ali (1999). Growth of potato cultivars in response to application of phosphate fertilizer. Annals of Applied Biology 135 (1), 431-438.

[19] Leikam, D. F., L. S. Murphy, D. E. Kissel, D. A. Whitney, and HC Moser (1983). Effects on nitrogen and phosphorus application method and nitrogen source on winter wheat grain yield and leaf tissue phosphorus. Soil Sci. Soc. Am. J. 47:530-535.

[20] Marschner H (1995). Mineral Nutrition of Higher Plants: Academic Press; (2nd). 889 p.

[21] O'Brien, P. J., Allen, E. J. and DM Firman (1998). A review of some studies into tuber initiation in potato (*Solanum tuberosum L.)* crops. The Journal of Agricultural Science 130 (03), 251-270.

[22] Olson, RA, AF, Dreir, GW Lowrey, and AD Flowerday (1956). Availability of phosphate carriers to small grains and subsequent clover in relation to: II. Concurrent soil amendments. Agronomy. Pp: 48:111-116.

[23] Phillips, A. B. and JR Webb (1971). *Production, marketing and use of P fertilizers*. In: *Fertilizer Technology and Use* (2nd Edition) SSSA, Madison, Wisconsin, USA.

[24] Qureshi, SA (1978). *Green revolution can be revitalized in Pakistan*. Paper presented in seminar on "Wheat Research and Production", held on August 1978 at Pakistan Agriculture Research Council, Islamabad.

[25] Rehm, G., G. Randall, J. Lamb, and R Eliason (2006). Fertilizing corn in Minnesota. FO-3790-C. Rev. 2006. Minnesota Cooperative Extension Service. St. Paul., MN. Available online http://www.extension.umn.edu/distribution/cropsystems/ DC3790.html (verified 14 Aug. 2009).

[26] Sanchez PA (2002). Soil fertility and hunger in Africa. Science 295, 2019–2020.

[27] Rengel Z. and P Marschner (2005). Nutrient availability and management in the rhizosphere: exploiting genotypic differences. New Phytologist 168 (2):305-312.

[28] Roman FD and T William (1993). Studied the effect of phosphorus behavior under different soil texture. *Soil Sci. J*., 158: 47-49.

[29] Sasson A (2012). Food security for Africa: an urgent global challenge. Agricultural Food Security PP: 1–16.

[30] Sims, A. L. and L. J. Smith (2002). Use of Starter Fertilizer to Reduce Broadcast Applications of Phosphorus. 2002 Sugar beet Research and Extension Reports. 33:94-99.

[31] Shapiro CA, RB Ferguson, GW Hergert, AR Dobermann, and CS Wortmann (2003). Fertilizer suggestions for corn. G74-174-A. Rev. Nov. 2003. Nebraska Coop. Ext. Serv., Univ. Nebraska, Lincoln. Available online at http://www.ianrpubs.unl.edu/epublic/pages/publicationD. jsp/publication=142 (verified 14 Aug. 2009).

[32] Sims, J. T. and, A. N Sharpley (2005). Phosphorus: Agriculture and the Environment. Madison: American Society of Agronomy, inc. Agronomy monograph no. 46. ISBN 0891181571, 1071p.

[33] Sleight DM, DH Sander, and GA Peterson (1984). Effect of fertilizer phosphorus placement on the availability of phosphorus. Soil Sci. Soc. Am. J. 48:336-340.

[34] Stark, JC, Westermann, DT and B Hopkins (2004). Nutrient management guidelines for Russet Burbank potatoes. Moscow: University of Idaho, College of Agricultural and Life Sciences. University of Idaho Bulletin; (840), 12 p.

[35] Statistical Analytical System, (2003). SAS/STAT users Guide for Personal Computers Version 9.1.3: SAS-Institute. Cary, North Carolina.

[36] Syers, J. K., A. E. Johnson, and D. Curtin (2008). Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soil phosphorus behavior with agronomic information. FAO Fertilizer of Plant Nutrition. Bull. 18. Food and Agriculture Organization of the United Nations, Rome.

[37] Tukaki JL and RL Mahler (1990). Evaluation of nutrient solution phosphorus concentration on potato plantlet tuber production under greenhouse conditions. Journal of Plant Nutrition 13 (1), 149-168.

[38] Walkley, A. and CA Black (1934). An examination of different methods for determining soil organic matter and the proposed modification by the chromic acid titration method. *Soil Sciences*, 37: 29-38.