Research Open

Aquaculture and Fisheries Studies

Volume 4 Issue 5

DOI: https://doi.org/10.31038/AFS.2022451

Research Article

# Influence of Phosphorus Fertilizer Rates on Grain Yield and Economic Benefits of Sorghum (*Sorghum bicolor* L.) in Case of Kersa District, South Western Ethiopia

**Habetamu Getinet[1]* and Obsa Atinafu[2]**

[1]Ethiopian Institute of Agricultural Research, Debre Markos Agricultural Research Center, Debre Markos, Ethiopia

[2]Ethiopian Institute of Agricultural Research, Debre Zeit Agricultural Research Center, Debre Zeit, Ethiopia

***Corresponding author:** Ethiopian Institute of Agricultural Research, Debre Markos Agricultural Research Center, Debre Markos, Ethiopia

**Received:** October 18, 2022; **Accepted:** October 25, 2022; **Published:** October 28, 2022

## Abstract

Depletion of soil fertility coupled with unbalanced fertilization of crops is one of the major constraints limiting crop yield in Ethiopia. Here therefore, afield experiment was undertaken at two sites (site-1 and site-2) on Nitisols of Kersa District, Southwestern Ethiopia to determine the effect of phosphorus fertilizer rate on grain yield and economic production of sorghum. The experiment consists of seven levels of P (0, 11.5, 23, 34.5, 46, 57.5 and 69 kg P ha$^{-1}$) including one treatment 46-40 kg ha$^{-1}$ PK along with uniform level of N (46 kgha$^{-1}$). The experiment was arranged in randomized complete block design (RCBD) having three replications. The collected data was subjected to ANOVA using SAS 9.3 version software. The results revealed that P fertilization brought significant effect on grain yield, biomass yield and harvest index at both sites. At site-1, the maximum grain yield (4517.0 kg ha$^{-1}$) and biomass yield (7134.3 kgha$^{-1}$) were obtained from combined fertilization of PK (46-40 kgha$^{-1}$), while the lowest grain yield (2212.6 kgha$^{-1}$) and biomass yield (5366.4 kgha$^{-1}$) were recorded from control plots. At site-2, the maximum grain yield (3716.1 kg ha$^{-1}$) and biomass yield (7760.7 kgha$^{-1}$) were also obtained from similar treatments (46-40 kgha$^{-1}$) PK, while the lowest grain yields (2399.5 kgha$^{-1}$) and biomass yield (5751.6 kgha$^{-1}$) were recorded from control plots. Application of (46-40 kgha$^{-1}$) PK produced the maximum net benefits with acceptable marginal rate of return at both sites. Therefore, we can recommend that integrated application of P and K at a rate of 46 -40 kg ha$^{-1}$ is better to improved yield and economical production of sorghum.

***Keywords:*** *Economic return, Sorghum, Phosphorus level, Yield*

## Introduction

Sorghum (*Sorghum bicolor* L.) belongs to the family Poaceae which is the fifth most important world cereal crops in production after wheat, rice, maize and barley. Because of its drought resistance and wide range of ecological adaptation, it is the crop of choice for dry regions and areas with low rainfall amount [1]. In most East African countries, sorghum is grown in between an altitude of 900 to 1,500 masl and in Ethiopia the crop grows all over the country across various agro ecologies from high altitude with sufficient amount of rainfall to low lands receiving low rainfall [1,2]. According to the report of [3], annually 1.8 million ha of land is allotted for sorghum production and 4.3 million ton of grain is produced in Ethiopia. Currently, the crop is used as raw material for industries beyond animal feed and human consumption. It is gaining commercial value in malting and brewing industries which indicates, the crop has multi-purposes in lower and mid altitude regions of Ethiopia and it is not only a staple food crop in the rural areas but also it is used primarily to prepare local foods including (injera, bread, thick porridge). In Ethiopia, this crop accounts for one-third of the total cereal crops production area and covers 16.36% of the total cultivated area [4]. However, currently the production is constrained by various factors majorly due to low soil fertility and improper utilization of fertilizer.

Fertilizers are naturally obtained or artificially produced nutrient sources that, when applied on the plant or to soil can supplement natural soil nutrients and augment crop growth and soil fertility for growth and development. Thus, application of fertilizer at proper time through proper method in balanced proportion shows better impact on crop productivity [5]. Among major macronutrients, phosphorus is one of the most important yields limiting plant nutrient next to nitrogen and is the second most deficient plant nutrient in the study area [6]. It plays an important role in many physiological processes such as photosynthesis, storage of energy and its transfer, respiration and cell enlargement, cell division etc. Minimum usage of P in relation to N has been identified as one of the major factors limiting higher crop yields. Therefore, phosphorus deficiency is a yield reducing factor if it not applied in adequate quantity. For instance, in wheat phosphorus deficiency reduces number tillers and plant leaf area by producing smaller and less number of leaves and at the end overall economy of the crop [7]. Among various factors, deficiency of nutrients is the most important bottleneck problem which directly contributes to reduce yield of cereal crops including sorghum. When phosphorus fertilizer is in optimum amount, gradually it increases the overall economy of sorghum crop [8]. Thus, to obtain maximum yield of crops it is mandatory to provide plant nutrients in optimum level of their nutrients requirement. Therefore, the present experiment was conducted (i) to evaluate the effect of phosphorus fertilizer rate on grain yield and (ii) to determine economics return of sorghum at Nitisols of Kersa district.

## Materials and Methods

### Description of Study Area

A field experiment was conducted in two sites during 2017/18 main cropping season on farmers' fields in Nitisols of Kersa District South-western Ethiopia. The experimental sites was geographically located at latitude of 7° 42' N, longitude 36° 59' E and an altitude of 1753 masl. The average minimum and maximum temperature was 11.6°C and 27.5°C, respectively. The area received an average annual rainfall of 1750 mm. The predominant soil type of the study area, in particular, is Nitisols which have a reddish brown in colour with moderately acidic in reaction. On average, the soil is deep and highly weathered well-drained, sandy clay in texture and strong to moderately acidic in a reaction as reported by [9]. The farming system of the area is cereal dominated such as maize, tef and sorghum. Soybean is also among the legume crops cultivated in the area.

## Treatments and Experimental Design

The experiment encompasses seven level of phosphorus fertilizer (0, 11.5, 23.0, 34.5, 46.0, 57.5, and 69 kg ha$^{-1}$ P) including one treatment 46-40 kg ha$^{-1}$ PK. The treatments were applied with respect to the treatment allocation. In all plots 46 kgha$^{-1}$ N was applied uniformly. Even though farmers are not growing sorghum without fertilizer, control treatment was included for comparison among the rest of the treatments. The treatments were arranged in a randomized complete block design (RCBD) replicated three times each. The experimental plot was gross plot area of 14.625 m$^2$ (3.75 m x 3.9 m), which accommodated 5 rows while the net plot area was 11.7 m$^2$ (3 m x 3.9 m). The spacing of 0.15 m and 0.75 m was used between plants and rows, respectively. High yielding Aba Melko sorghum variety which is the most promising hybrid released by Jimma Agricultural Research Centre and adapted to the agro-ecology of the area was used as a test crop. The seed was drilled in prepared row manually with spacing of 0.75 m between rows and 0.15 m between plants [10].

Planting was done based on local farmers planting calendar. Phosphorus was applied based on the treatments assigned once at planting and full doses of recommended nitrogen fertilizer (46 kgha$^{-1}$) were applied in splits half rate during planting and the remaining half dose at knee stages uniformly for all plots. Urea, Triple Super Phosphate (TSP) and Murate of Potash (KCl) were used as sources of fertilizer for supplying N, P and K nutrients respectively. All agronomic practices including weeding and hoeing were done uniformly for all plots according to agronomist's recommendation (Table 1).

### Data Collection

Grain yield of sorghum from each net plot were harvested when the crop fully matured. The weighted grain was finally adjusted to (12.5%) which is the standard moisture contents of cereal crops. Biomass yield of sorghum from each harvestable plot was harvested at the ground level from each plot were measured and reported on a hectare basis.

**Table 1:** Treatments used in the present study.

| Treatments | Fertilizer rate (kg ha$^{-1}$) | | |
|---|---|---|---|
| | N | P | K |
| $T_1$ | 46 | 0.0 | 0 |
| $T_2$ | 46 | 11.5 | 0 |
| $T_3$ | 46 | 23.0 | 0 |
| $T_4$ | 46 | 34.5 | 0 |
| $T_5$ | 46 | 46.0 | 0 |
| $T_6$ | 46 | 57.5 | 0 |
| $T_7$ | 46 | 69.0 | 0 |
| $T_8$ | 46 | 46.0 | 46 |

Harvest Index (%) was determined as a ratio of grain yield to above ground biological yield on dry weight basis in percentage [11] as described in the following formula.

$$HI = \left(\frac{grain\ yield}{above\ ground\ biomass}\right) * 100$$

### Data Analysis

The collected data was analyzed using analysis of variance (ANOVA) appropriate to randomized complete block design using statistical analysis system [12] 9.3 Version software. The interpretations were made following the procedure described by [13]. Least Significant Difference (LSD) test at 5% probability level was used for treatment mean comparison when the ANOVA showed significant differences among treatments.

### Economic Analysis

The open market price for sorghum (6.42 birr kg$^{-1}$) and the cost incurred for P and K fertilizers (TSP=18.5 birr kg$^{-1}$) and potassium chloride (KCl=12.2 birr kg$^{-1}$). Grain yield was adjusted to 10% downward due to management difference to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment [14]. The dominance analysis procedure was done as described by [14] to select potentially profitable treatments. Dominance analysis was also done to the selection of treatments ranked in increasing order of total variable costs. The marginal rate of return (MRR (%)) was calculated by dividing the change in net benefit to the change in variable costs. 100% MRR means for every 1 birr invested in different cost of fertilizer and maize seed, farmers can expect to recover 1 birr and obtain an additional1 birr [14].

## Results and Discussion

### Grain Yield

The ANOVA result showed that grain yield of sorghum was significantly influenced due to various phosphorus levels at both sites. The highest grain yield at site-1 (4517.0 kgha$^{-1}$) and at site-2 (3716.1 kgha$^{-1}$) was obtained from plots treated with (46-40 kg ha$^{-1}$) PK while the lowest grain yield at site-1 (2212.6 kgha$^{-1}$) and at site-2 (2399.5 kg ha$^{-1}$) was obtained from zero level of phosphorus. The result revealed that yield increase as increasing levels of phosphorus fertilizer which might be due to higher rate of photosynthesis and better crop health which ultimately increased the final grain yield. The maximum yield recorded with P and K fertilization in the current study is most likely an indicator due to their deficiency in the field soil especially that of P. Plants showed normal growth with the application of phosphorus and resulted in improved agronomic traits which lead toward improved grain yield as reported [15]. The current result is in line with the finding of [16]. The maximum yield obtained from PK treated plots might be also due to their synergistic effect, the efficiency of these elements is enhanced resulting in increased crop productivity. So, maximum accumulation of PK nutrients gave highest yield. The current result is in conformity with the finding of [17] who reported that grain yield at maximum accumulation of nutrient occurs when nutrient rate is increased.

### Biomass Yield

The ANOVA result revealed that biomass yield increased consistently with increasing phosphorus rates from 0 to 46 kg ha$^{-1}$. Accordingly, plots treated with (46-40 kgha$^{-1)}$ PK produced maximum biological yield (7134.3 kg ha$^{-1}$) which obtained 24.78% yield advantages compared with zero level of phosphorus. The maximum biomass yield recorded from the highest and balanced fertilization might be due to the involvement of each nutrient in supporting the physiological functions of plants through promoting leaf expansion, photosynthesis, and dry matter accumulation. While in control plots (absence of phosphorus fertilization) minimum biological yield (5366.4 kg ha$^{-1}$) was recorded. The lower biomass yields recorded from the control plot revealed that neither sole application nor lower rates of P is sufficient to boost sorghum production significantly and to maintain soil fertility status at optimum level. This finding is in line with the finding of [18] who ascertained that increasing application of fertilizer nutrients (N and P) increases grain yield and biomass weight of sorghum significantly. Similarly [19] also confirmed that fertilizer N and P has contributed more than any other fertilizer towards increasing yield of grain crops and biomass yield.

In general, as increasing rates of P up to certain value increased grain and biomass yield. Optimum nutrition of P is critical for root development, increased stalk and stem strength, increased flowering and seed production, uniform and early crop maturity, improved crop quality, and increased resistance to plant diseases thereby all over grain yield and biomass weight of sorghum. The current result is in conformity with the finding of [20]. Moreover, [21] also reported that combined use of N and K significantly increased most growth parameters of sorghum which enhances high biomass production.

### Harvest Index (HI (%))

The physiological efficiency or translocation of assimilates from source into economic sinks is known as Harvest Index (HI). The value of harvest index showed significant effect due to different levels of phosphorus fertilizer. In the present experiment, with increasing the rate of phosphorus fertilizer up to 46 kgha$^{-1}$ harvest index increased significantly. At site-1 the maximum harvest index value (48.0%) was observed from plots treated with 57.5 kg ha$^{-1}$ P, while at site 2 the maximum harvest index (47.8%) was observed from combined fertilization of PK at rate of (46-40) kgha$^{-1}$. This indicates that significantly lower biomass partitioning to grain production when P was increased beyond certain level. The lower mean HI values in this experiment with the higher P application might indicate the need for the enhancement of biomass partitioning through genetic improvement (Table 2).

### Economics of Fertilizer Use

From the treatments used, PK nutrients increased the financial returns relative to that achieved without them which gained net benefit of 23, 273.23 ETBha$^{-1}$ with MRR 520.18% at site1 and at site-2 net benefit of 18,645.63 ETBha$^{-1}$ with MRR 211.97% as shown (Tables 3 and 4). This recommendation was in conformity with the manual of [14], which reported that farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum acceptable rate of return. The current result is also parallel with the finding of [22] who shares the same opinion after analyzing the financial data of fertilizer use in cotton. Therefore, the present study revealed that combined use of PK under constant value of N fertilizer is better in economic terms for maximum sorghum production.

**Table 2:** Effect of Phosphorus fertilizer level on grain yield, biomass yield and HI of sorghum.

| Treatments (P rate (kgha$^{-1}$)) | Grain yield (kgha$^{-1}$) | | Biomass yield (kgha$^{-1}$) | | Harvest Index (%) | |
|---|---|---|---|---|---|---|
| | Site-1 | Site-2 | Site-1 | Site-2 | Site-1 | Site-2 |
| $T_1$=Control | 2212.6$^{f}$ | 2399.5$^{d}$ | 5366.4$^{c}$ | 5751.6$^{d}$ | 43.3$^{bcd}$ | 41.77$^{bcd}$ |
| $T_2$=11.5 | 2663.2$^{e}$ | 2574.1$^{cd}$ | 6465.7$^{ab}$ | 6690.6$^{c}$ | 40.0$^{d}$ | 36.98$^{d}$ |
| $T_3$=23.0 | 3148.6$^{d}$ | 2820.1$^{bcd}$ | 6425.2ab | 7258.1$^{b}$ | 41.8cd | 38.99$^{cd}$ |
| $T_4$=34.5 | 3334.5$^{d}$ | 3146.0$^{abc}$ | 6238.0$^{b}$ | 7516.8$^{ab}$ | 45.4$^{abc}$ | 41.75$^{bcd}$ |
| $T_5$=46.0 | 3575.5$^{cd}$ | 3150.9$^{abc}$ | 6334.8$^{b}$ | 7601.1$^{ab}$ | 46.5$^{ab}$ | 41.50$^{bcd}$ |
| $T_6$=57.5 | 3965.2$^{bc}$ | 3209.1$^{abc}$ | 6475.1$^{ab}$ | 7373.2$^{ab}$ | 48.0$^{a}$ | 43.01$^{abc}$ |
| $T_7$=69.0 | 4091.8$^{ab}$ | 3537.6$^{ab}$ | 6527.9$^{ab}$ | 7649.0$^{ab}$ | 47.2$^{ab}$ | 46.17$^{ab}$ |
| $T_8$=46-40 (P-K) | 4517.0$^{a}$ | 3716.1$^{a}$ | 7134.3$^{a}$ | 7760.7$^{a}$ | 46.21$^{abc}$ | 47.80$^{a}$ |
| Mean | 3438.54 | 3056.68 | 6370.93 | 7200.14 | 44.79 | 42.25 |
| LSD (0.05) | 434.29 | 737.05 | | 426.55 | 4.50 | 5.45 |
| CV (%) | 7.21 | 13.77 | 6.87 | 3.38 | 5.73 | 7.36 |

 ***ISSN: 2771-8107***

**Table 3:** Partial budget analysis for fertilizer use in sorghum production at site-1.

| Treatments (P rate (kg ha$^{-1}$)) | GY (Kg ha$^{-1}$) | Adj.GY (Kg ha$^{-1}$) | GFB (ETB ha$^{-1}$) | TVC (ETB ha$^{-1}$) | NB (Birr ha$^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|
| $T_1$=0 | 2212.6 | 1991.34 | 12784.40 | 0 | 12784.4 | - |
| $T_2$=11.5 | 2663.2 | 2396.88 | 15387.97 | 462.5 | 14925.47 | 462.93 |
| $T_3$=23.0 | 3148.6 | 2833.74 | 18192.61 | 925.0 | 17267.61 | 506.41 |
| $T_4$=34.5 | 3334.5 | 3001.05 | 19266.74 | 1387.5 | 17879.24 | 132.24 |
| $T_5$=46.0 | 3575.5 | 3217.95 | 20659.24 | 1850.0 | 18809.24 | 201.08 |
| $T_6$=57.5 | 3965.2 | 3568.68 | 22910.93 | 2312.5 | 20598.43 | 386.85 |
| $T_7$=69.0 | 4091.8 | 3682.62 | 23642.42 | 2775.0 | 20867.42 | 58.16 |
| $T_8$=46-40 P-K | 4517.0 | 4065.3 | 26099.23 | 2826.0 | 23273.23 | 520.18 |

Where; Adj.GY: Adjusted Grain Yield down to 10%, GY: Grain Yield, GFB: Gross Field Benefit, TVC: Total Cost that Varies, NB: Net Benefit, MRR: Marginal Rate of Return and ETB: Ethiopian Birr.

**Table 4:** Partial budget analysis for fertilizer use in sorghum production at site-2.

| Treatments (P rate (kg ha$^{-1}$)) | GY (Kg ha$^{-1}$) | Adj.GY (Kg ha$^{-1}$) | GFB (ETB ha$^{-1}$) | TVC (ETB ha$^{-1}$) | NB (ETB ha$^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|
| $T_1$=0 | 2399.5 | 2159.55 | 13864.31 | 0 | 13864.31 | - |
| $T_2$=11.5 | 2574.1 | 2316.69 | 14873.15 | 462.5 | 14410.65 | 118.13 |
| $T_3$=23.0 | 2820.1 | 2538.09 | 16294.54 | 925.0 | 15369.54 | 207.33 |
| $T_4$=34.5 | 3146.0 | 2831.40 | 18177.59 | 1387.5 | 16790.09 | 307.15 |
| $T_5$=46.0 | 3150.9 | 2835.81 | 18205.90 | 1850.0 | 16355.90 | - |
| $T_6$=57.5 | 3209.1 | 2888.19 | 18542.18 | 2312.5 | 16229.68 | - |
| $T_7$=69.0 | 3537.6 | 3183.84 | 20440.25 | 2775.0 | 17665.25 | 310.39 |
| $T_8$=46-40 (P-K) | 3716.1 | 3344.49 | 21471.63 | 2826.0 | 18645.63 | 211.97 |

Where; Adj.GY: Adjusted Grain Yield down to 10%, GY: Grain Yield, GFB: Gross Field Benefit, TVC: Total Cost that Varies, NB: Net Benefit, MRR: Marginal Rate of Return and ETB: Ethiopian Birr.

## Conclusion

Based on the results obtained, we can conclude that as increasing rate of phosphorus fertilization increased the productivity of sorghum in constantly. Application of phosphorus and potassium fertilizer at a rate of 46-40 kg ha$^{-1}$ has been found agronomical optimum for increasing the yield and yield components of sorghum. The result further revealed that the existing blanket recommendation of 46 kg N ha$^{-1}$ and 40 kg K ha$^{-1}$ has been found sub-optimal in response to the ever-increasing soil fertility depletion of the study area.

Nutrients with high harvest index values remove more of that nutrient from the field than nutrients with low harvest index values and suggest a looming soil fertility crisis if adequate adjustments are not made in usage of balanced nutrients increases productivity.

Economic analysis was done by assuming total variable cost, net benefit, dominant treatments and marginal rate of return. Hence, the result indicated that application of phosphorus in combination with K at a rate of 46-40 kg ha$^{-1}$ produce maximum net benefit at both sites. Therefore, the present study revealed that the combined use of P and K fertilizer is better in economic terms for growing sorghum production under rain fed condition.

## Acknowledgements

The authors acknowledge the Ethiopian Institute of Agricultural Research for funding of this study. Staffs of Natural Resource Management of Jimma Agricultural Research Center (JARC) are highly acknowledged for their support during the study. Soil and Plant Tissue Analysis Laboratory of Jimma Agricultural Research Centers is also duly acknowledged for the analysis of experimental samples.

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**Citation:**

Getinet H, Atinafu O (2022) Influence of Phosphorus Fertilizer Rates on Grain Yield and Economic Benefits of Sorghum (*Sorghum bicolor* L.) in Case of Kersa District, South Western Ethiopia. *Aquac Fish Stud* Volume 4(5): 1-5.