



Research article

Response of yield and quality of soybean [*Glycine max* (L.) Merrill] varieties to blended NPSZnB fertilizer rates in Northwestern EthiopiaAsmachew Agegn^a, Yayeh Bitew^{b,*}, Dereje Ayalew^b^a Amhara Agricultural and Rural Development Bureau, Guangua Agricultural Office, Chagni, Ethiopia^b Bahir Dar University, College of Agriculture and Environmental Science, P.O. Box 5501, Bahir Dar, Ethiopia

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ABSTRACT

The national productivity of soybean is lower than that of world's productivity due to lack of appropriate agronomic practices. A field experiment was carried out in 2020/2021 cropping season at Guangua district, Northwestern Ethiopia to determine the effect of blended NPSZnB (Nitrogen, Phosphorus, Sulfur, Zinc and Boron) fertilizer rates on seed yield and quality of soybean varieties. Five levels of blended NPSZnB fertilizer (0, 50, 100, 150 and 200 kg ha⁻¹) and three soybean varieties (Pawe-01, Pawe-02 and Pawe-03) were arranged in factorial and laid out in randomized complete block design with three replications. Data on soybean agronomic attributes and soybean seed quality were collected and analyzed using SAS software. Results revealed most growth, yield, yield components and quality traits of soybean were significantly affected by varieties, blended fertilizer rates and by their interaction. Planting variety Pawe-03 with the application of 100 kg ha⁻¹ NPSZnB gave the highest grain yield (2.88 t ha⁻¹) and protein content (41.50%). Maximum oil content (24.50%) was recorded when variety Pawe-01 was planted with the application of 100 kg ha⁻¹ NPSZnB. Planting Variety Pawe-03 with application of 100 kg ha⁻¹ NPSZnB gave the highest net benefit (74953.56 birr ha⁻¹). In conclusion, planting Pawe-03 soybean variety with the application of 100 kg ha⁻¹ NPSZnB gave significantly highest seed yield, protein content and profitability and recommended for soybean production in Northwestern agro-ecologies of Ethiopia. It is suggested that this experiment should be repeated in various agro ecologies with various soybean varieties.

1. Introduction

Soybean is widely distributed in most parts of the World and has a lot of potentials in Africa (Hartman et al., 2011). It was first introduced to Ethiopia in 1950's because of its nutritional value, multiuse (human food, livestock feed, manufacturing purposes), source of bio-energy and wider adaptability (Atnaf et al., 2013). Plant proteins provide nearly 65% of the world protein supply with 45–50% coming from legumes and cereals to population of developing countries and vegetarians of industrialized nation (Duane and Ted, 2003). Among grain legumes, soybean has the highest protein and oil content. The soybean seed on an average contains 40% protein, 20% oil, 35% carbohydrate and about 5% ash, which determine the economic worth of seed in the glob (Thomas and Erostat, 2008).

Soybean has become a crop of growing in different agro ecological areas of Ethiopia. Currently, the area covered by soybean production is 54,543 ha with total production of 125,623t (CSA, 2020) and the national average productivity of 2.30 t ha⁻¹ which is lower than that of the world

average productivity (2.79 t ha⁻¹) (FAOSTAT, 2019). Thus, the country faced serious lack of oil seed for the huge number of oil industries established recently and in turn couldn't secure food oil for consumption. The major reasons for low productivity of soybean in Ethiopia were low varietal stability, narrow genetic base of cultivar, insect pests and diseases, multi-nutrient deficiencies, low fertilization, limited access to improved soybean seed, and poor agronomic practices (Hailemariam and Tesfaye, 2018). Among these various yield limiting factors; limited access in improved soybean varieties seed (Ouma et al., 2006) and multi-nutrient deficiencies (nitrogen, phosphorus, sulfur, zinc and boron) (Rao and Reddy, 2010) are considered of great importance. The improved soybean varieties have their own agro ecological requirements to attain highest yield that may vary with the genotypes, management activities and geographical locations (Isah et al., 2014; Wondimu et al., 2016). Thus, selecting the best varieties in specific locations is necessary for better soybean production and in return to increase household income.

In Ethiopia currently more than 25 different soybean varieties were released and available on production (MoANR, 2016). The improved

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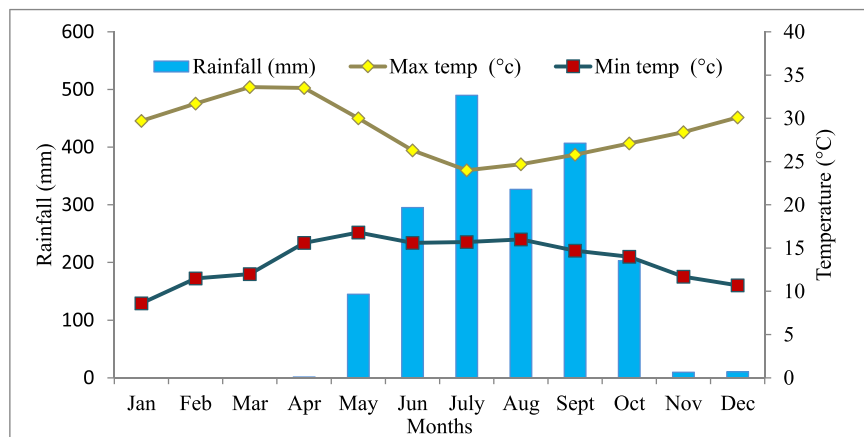


Figure 1. Mean monthly rainfall, maximum and minimum temperatures of the experimental site during 2020.

Table 1. Soil physical and chemical properties of experimental site before sowing in 2020.

Soil properties	Units	Values	Rating
Sand	%	35.64	
Clay	%	28.00	
Silt	%	36.36	
Textural class	-		clay loam ^a
PH		5.14	strongly acidic ^b
Organic carbon	%	1.99	high ^c
Organic matter	%	3.42	medium ^d
Total nitrogen	%	0.17	Low ^e
Cation exchange capacity	meq/100g	22.50	medium ^e
Available phosphorus	mg/kg	1.40	very low ^f
Extractable sulfur	mg/kg	3.50	low ^g
Extractable boron	mg/kg	0.45	low ^g
Extractable zinc	mg/kg	0.30	low ^g
Extractable Potassium	(Cmol (+))/kg	0.12	very low ^e
Extractable calcium	(Cmol (+))/kg	8.00	medium ^e
Extractable magnesium	(Cmol (+))/kg	4.00	medium ^e
Extractable sodium	(Cmol (+))/kg	0.14	low ^e

^a Ryan and Rashid (2001).
^b Hazelton and Murphy (2016).
^c Taddesse (1991).
^d EthioSIS (2014).
^e Landon (1991).
^f Olsen et al. (1954).
^g Jones (2019).

soybean varieties recently released around the study area were Pawe-01, Pawe-02 and Pawe-03. In the order of Pawe-02, Pawe-01 and Pawe-03 constitutes important traits including high oil content (23%), protein content (42%) and high canopy coverage (to regulate soil fertility) (MoANR, 2016). The potential and attainable yield of the recently released soybean are on average up to 6 t ha⁻¹ and 2.9 t ha⁻¹, respectively (Deresse, 2019). However, actual yield of the crop in the country

Table 2. Description of soybean varieties (MoANR, 2016).

Soybean varieties	Altitude (m.a.s.l)	Rainfall (mm)	Growth habit	Maturity period (days)	Year of release	Productivity (t ha ⁻¹)	
						On RS	On FF
Pawe-01 (PARC-2013-2)	520–1800	460–1600	Indeterminate	110–120	2015	2.4	1.8
Pawe-02 (PARC-2013-3)	520–1800	460–1600	Indeterminate	110–120	2015	2.6	1.8
Pawe-03 (TGX-1987-62F)	520–1800	460–1600	Indeterminate	119	2016	2.3	2.1

RS, on research site and FF, on farmer's field.

Table 3. The main effects of varieties and blended NPSZnB fertilizer rates on vegetative growth of soybean at Guangua district, North western Ethiopia in 2020.

Source of variations	NPBPP	PH	PL
Varieties			
Pawe 01	5.47	55.67	3.39 ^a
Pawe 02	5.87	58.30	3.47 ^a
Pawe 03	5.67	59.80	2.97 ^b
LSD (0.05)	NS	NS	0.25 ^{**}
SE±	0.29	1.25	0.08
NPSZnB rates (kg ha⁻¹)			
0	4.11 ^b	48.23 ^c	3.11
50	5.56 ^a	58.17 ^b	3.32
100	5.89 ^a	61.73 ^{ab}	3.38
150	6.22 ^a	58.12 ^b	3.14
200	6.56 ^a	63.37 ^a	3.41
LSD(0.05)	1.09 ^{**}	4.69 ^{***}	NS
SE±	0.37	1.60	0.11
CV (%)	19.89	8.38	10.30

NPBPP, number of primary branch per plant; PH, plant height in cm; PL, pod length in cm. Means with the same letter(s) in column per individual factors are not significantly different at P = 0.05, LSD – least significant difference, CV – coefficient of variation, SE -standard error, *** very highly significant at P = 0.0001, ** highly significant at = 0.01 and NS = non-significant difference at P = 0.05.

and study area are 2.30 t ha⁻¹ (CSA, 2020) and 1.5 t ha⁻¹ (GDAO, 2019), respectively. This low productivity occurred due to improper and limited utilization of improved soybean production varieties (PARC, 2010). According to Mulugeta (2011), limited utilization of improved varieties gave low production and productivity of soybean.

Soil fertility reduction is one of the major challenges to crop production and productivity in Ethiopia (Amsal and Tanner, 2001). Soil fertility depletion in smallholder farmers is the basic root cause for declining production and productivity of soybean (Mafongoya et al.,

2006). Use of blended or balanced fertilizers containing both macro and micronutrients is one of the key solutions suggested to resolve the soil fertility problems. Starting from 1960's, fertilizer use in Ethiopia has focused on the application of Urea and Di-ammonium phosphate (DAP) for almost all crops, soil types and agro ecologies (Tamene et al., 2017). This unbalanced application of plant nutrients may aggravate the depletion of other important nutrient elements in soils (K, Mg, Ca, and S) and micronutrients (Wassie and Shiferaw, 2011). The soil fertility mapping project in Ethiopia reported that deficiency of K, S, Zn, B, Fe and Cu in addition to N and P in major Ethiopian soils were common (Ethio-SIS, 2014). Ethio-SIS (2014) and Kassahun (2015) revealed seven soil nutrients (N, P, K, S, Fe, Zn and B) were found to be deficient in most soils of Amhara region. Depletion of soil nutrients other than N and P could be additional reason for the observed decrease in productivity of soybean (Wassie and Tekalign, 2013). Eight (NPKSB, NPKSFeZnB, NPKSZNb, NPSB, NPSFeB, NPSFeZn, NPSFeZnB and NPSZNb) blended fertilizers were recommended in Amhara region, among these NPSB and NPSZNb have been utilized in Guangua district as a blanket recommendation (ATA, 2015). However, the optimum rates of these blended fertilizers for soybean production have not been investigated yet. The response of soybean to application of blended fertilizer varies with varieties, rainfall, soils, and management practices. Thus, the objective of this study was to examine the effect of blended

NPSZNb fertilizer rate on seed yield and quality of soybean varieties in Northwestern Ethiopia.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted during 2020/2021 main cropping season in Guangua District, northwestern Ethiopia with the Latitude: 11° 00' 0.00" N, Longitude: 36° 19' 60.00" E and an altitude varies from 1304 to 2160 m.a.s.l. Major crops grown in the study area are maize (*Zea mays* L.), finger millet (*Eleusine coracana* L.), teff (*Eragrostis teff* Zucc.), soybean (*Glycine max* L. Merrill), haricot bean (*Phaseolus vulgare* L.), ground nut (*Arachis hypogaea* L.), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), which are cultivated during the main rainy season. The area is characterized by a uni-modal rainfall pattern with high and torrential rainfall that extends from May to October. However, the peak season is from June to September (GDAO, 2019). Annual rainfall and average annual temperature during the experimental year was collected from the north-western Ethiopia meteorology station office in Bahir Dar, Ethiopia after it was collected from the study area. The area receives annual rainfall of with the mean annual minimum temperature of 13.6 °C and mean annual maximum temperature of 28.7 °C (Figure 1).

Table 4. The main and interaction effects of varieties and NPSZNb rates on yield and yield components of soybean at Guangua district, North western Ethiopia in 2020.

Variety	Fertilizer rate kg ha ⁻¹	NPPP	NSPP	AGBY	HSW	GY	HI
Varieties							
Pawe- 01		32.53 ^b	2.47 ^b	4741.58 ^c	11.28 ^b	1785.40 ^b	38.12 ^b
Pawe- 02		32.27 ^b	2.33 ^b	5416.19 ^b	11.8 ^a	1675.15 ^c	31.20 ^c
Pawe- 03		35.87 ^a	2.8 ^a	5693.97 ^a	8.19 ^c	2297.28 ^a	40.51 ^a
LSD (0.05)		1.18 ^{***}	0.32 [*]	2.15 ^{***}	0.13 ^{***}	2.19 ^{***}	0.8 ^{***}
SE±		0.40	0.11	0.74	0.04	0.75	0.27
NPSZNb rates							
	0	26.56 ^c	2.33	3535.98 ^c	10.50 ^a	1162.43 ^c	35.72 ^c
	50	32.56 ^b	2.56	5423.28 ^c	10.50 ^a	2062.17 ^c	38.37 ^b
	100	37.78 ^a	2.44	5952.38 ^b	10.67 ^a	2543.77 ^a	42.33 ^a
	150	32.56 ^b	2.44	4960.31 ^d	10.23 ^b	1599.16 ^d	32.60 ^e
	200	38.33 ^a	2.89	6547.62 ^a	10.21 ^b	2228.84 ^b	34.02 ^d
	LSD(0.05)	1.53 ^{***}	NS	2.78 ^{***}	0.17 ^{***}	2.82 ^{***}	1.04 ^{***}
	SE±	0.52	0.14	0.96	0.05	0.97	0.35
Variety by NPSZNb interaction rate							
Pawe- 01	0	22.33 ^g	2.67	2874.60 ^j	11.40 ^c	1030.16 ^j	38.75 ^d
	50	35.33 ^c	2.67	5357.14 ^f	12.10 ^{ab}	2321.43 ^d	43.33 ^b
	100	37.00 ^{bc}	2.00	4761.90 ^g	11.10 ^d	2043.65 ^e	42.92 ^b
	150	29.67 ^e	2.00	4761.90 ^g	10.40 ^f	1488.1 ^f	31.25 ^{gh}
	200	38.33 ^{ab}	3.00	5952.38 ^c	11.40 ^c	2043.65 ^e	34.33 ^f
Pawe- 02	0	27.60 ^{ef}	2.00	3668.25 ⁱ	12.10 ^{ab}	1089.68 ⁱ	32.50 ^g
	50	26.67 ^f	2.33	4761.90 ^g	10.8 ^c	1265.87 ^h	26.58 ⁱ
	100	37.67 ^{abc}	2.33	6547.62 ^c	12.30 ^a	2710.67 ^b	42.97 ^b
	150	32.33 ^d	2.33	5357.14 ^f	11.90 ^b	1265.87 ^h	23.63 ^j
	200	37.00 ^{bc}	2.67	6746.03 ^b	11.90 ^b	2043.65 ^e	30.30 ^h
Pawe- 03	0	29.67 ^e	2.33	4065.08 ^h	8.00 ^h	1367.46 ^g	35.91 ^{ef}
	50	35.67 ^c	2.67	6150.79 ^d	8.60 ^g	2599.21 ^c	45.20 ^a
	100	38.60 ^{ab}	3.00	6547.62 ^c	8.60 ^g	2876.98 ^a	41.11 ^c
	150	35.67 ^c	3.00	4761.90 ^g	8.40 ^g	2043.52 ^e	42.92 ^b
	200	39.67 ^a	3.00	6944.44 ^a	7.33 ⁱ	2599.21 ^c	37.43 ^d
LSD(0.05)		2.59 ^{***}	NS	7.32 ^{***}	0.29 ^{***}	4.83 ^{***}	1.75 ^{***}
SE±		0.91	0.24	1.66	0.10	1.68	0.62
CV (%)		4.72	17.01	0.05	1.68	0.15	2.93

NPPP, number of pods per plant; NSPP, number of seeds per pod; AGBY, above ground biomass yield in kg ha⁻¹; HSW, hundred seed weight in grams; GY, grain yield in kg ha⁻¹; HI, harvest index in %. Means with the same letter(s) in column per individual factors are not significantly different at P = 0.05, LSD – least significant difference, CV – coefficient of variation, SE -standard error, *** very highly significant at P = 0.0001, * Significant at P = 0.05 and NS = non-significant difference at P = 0.05.

To characterize the general soil property of the experimental site, soil samples at 0–20 cm soil depth were collected from five randomly selected spots before planting. The five soil samples from the experimental site were composited, air dried and sieved through a 2 mm sieve and finally submitted to Amhara National Regional State (ANRS) Bureau of Agriculture soil laboratory and soil improvement center for soil nutrient analysis. Soil PH was determined from the filtered suspension of 1:2.5 soils water ratio to potassium chloride (KCl) solution using a glass electrode attached to the digital PH meter (Maclean, 1965). The textural class of the soil was determined by the hydrometer method (Juo, 1979). The organic carbon and total soil nitrogen were determined by following the methods of Walkely and Black (1934) and Kjeldahl method (Bremner and Mulvaney, 1982), respectively. Available P was determined by extraction with 0.5M Sodium bicarbonate (NaHCO₃) according to the method of Olsen et al. (1954). Exchangeable potassium was analyzed with a flame photometer after extracting the potassium from the soil with 1N ammonium acetate at 7 PH (Hesse, 1971). Cation exchange capacity was determined by summation (Hazelton and Murphy, 2016). Zinc and Boron were determined by DPTA (Whitney, 1998) and hot water (Watson et al., 1998), respectively. The results of the soil laboratory analysis are discussed in Table 1 section 3.1.

2.2. Experimental test materials

Three improved soybean varieties (Pawe - 01, Pawe - 02 and Pawe - 03) collected from Pawe Agricultural Research Center (PARC) (Table 2) were used for the study. These varieties were selected based on their utility with farmers, desirable characters and production potentials (Table 2). Recently used blended NPSZnB fertilizer (16.9% N, 33.8% P₂O₅, 7.3% S, 2.23% Z and 0.67% B) was used as a source of fertilizer.

2.3. Treatments and experimental design and planting procedures

The treatments were factorial combinations of five blended NPSZnB fertilizer rates (0, 50, 100, 150, 200 kg ha⁻¹) and three soybean varieties (Pawe - 01, Pawe - 02 and Pawe - 03) with a total of 15 treatments. The NPSZnB rates for the treatment were fixed based on the national blanket recommendations of di-ammonium phosphate (DAP) (100 kg ha⁻¹). The experiment was laid out in 3 × 5 factorial arrangements in randomized complete block design with three replications. The gross and the net plot size were 3 m × 3 m (9 m²) and 2.8 m × 1.8 m, respectively. The distance

between adjacent blocks and plots were 1 m and 0.5 m, respectively. The experimental field was tilled by oxen for three times and leveled manually. After the required seed bed preparations, soybean varieties were sown on July 13/2020 at the recommended seed rate of 60 kg ha⁻¹. Sowing was done manually with inter- and intra-row spacing of 60 cm and 5 cm, respectively. All Blended NPSZnB fertilizer rates were applied (drilling) at planting time. Nitrogen at the rate of 30 kg ha⁻¹ was applied at sowing time in the form of UREA to all plots except controls. All necessary agronomic crop management practices (like cultivation, weeding) were carried out uniformly for all plots as per the recommendation for the crop. The crop was harvested manually when 90% of the leaves and pods turned yellow and sun dried until it gets constant dry weight before threshing. Threshing was done individually for each plot manually.

2.4. Data collection

2.4.1. Soybean agronomic attributes

Plant height (cm) was measured from the mean of ten plants randomly sampled from the net plot of each plot. Numbers of branches per plant was obtained from ten randomly sampled primary branches of the net plot. The length of pods was measured by taking the mean of ten pods selected randomly from the net plot. Total numbers of pods per plant and total numbers of seeds per pod were obtained by taking the mean of ten randomly sampled plants and pods, respectively from the net plot. The total above ground-biomass from the net plot area of each plots was harvested and sun-dried for two weeks with an average air temperature of 25–27 °C till complete drying was attained. Then grain yield was separated and determined from the total biomass yield. The grain yield was then dried, threshed, cleaned and adjusted to the 13% moisture content. Harvest index was determined by dividing the economic yield with total dry biomass yield as indicated in Eq. (1).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Total Dry biomass yield}} \times 100 \quad (1)$$

2.4.2. Soybean grain quality analysis

The soybean seed quality was analyzed for protein and oil contents. The crude protein content was performed by total nitrogen determination according to the micro Kjeldahl method, technique 920.87 using a 6.25 conversion factor and expressed in dry matter (%) (AOAC, 1990).

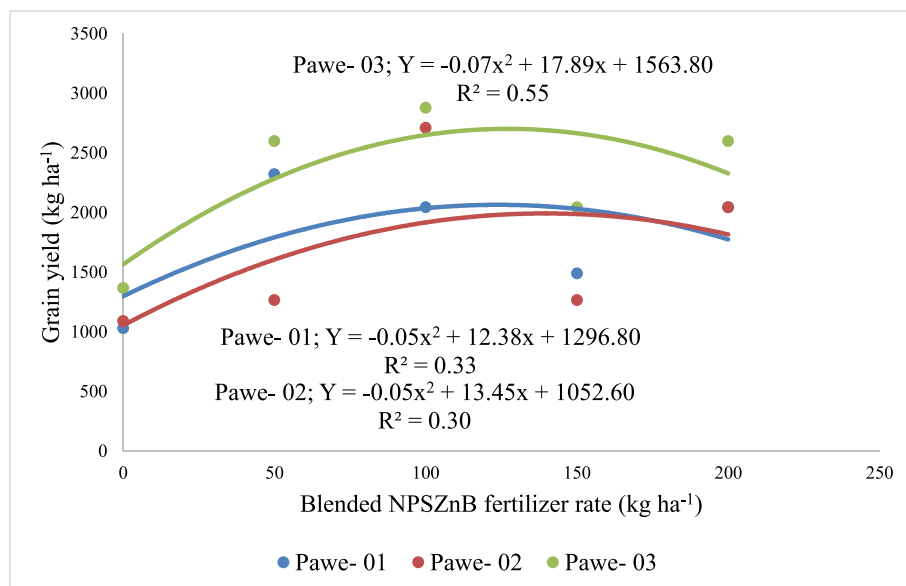


Figure 2. Polynomial regression analysis of soybean varieties grain yield as affected by NPSZnB fertilizer rates.

Table 5. Effect of blended NPSZnB fertilizer rates and varieties on quality of soybean seed at *Guangua* district, North western Ethiopia in 2020.

Variety	NPSZnB fertilizer rates (kg ha ⁻¹)	Crude protein (%)	Oil (%)
Variety			
Pawe- 01		38.78 ^c	23.86 ^a
Pawe- 02		39.48 ^b	23.30 ^b
Pawe- 03		41.12 ^a	20.36 ^c
LSD(0.05)		0.27***	0.09***
SE±		0.09	0.02
NPSZnB fertilizer rates (kg ha⁻¹)			
	0	39.60 ^b	22.70 ^a
	50	40.30 ^a	22.13 ^d
	100	39.80 ^b	22.47 ^c
	150	39.77 ^b	22.67 ^{ab}
	200	39.50 ^b	22.57 ^{bc}
LSD(0.05)		0.35**	0.11***
SE±		0.12	0.03
Variety by NPSZnB fertilizer rate interaction			
Pawe- 01	0	38.00 ^h	24.20 ^b
	50	40.40 ^{cd}	22.90 ^f
	100	37.90 ^h	24.50 ^a
	150	38.80 ^g	23.80 ^c
	200	38.80 ^g	23.90 ^c
Pawe- 02	0	39.70 ^{ef}	23.40 ^e
	50	39.70 ^{ef}	23.30 ^e
	100	40.00 ^{de}	22.80 ^f
	150	39.40 ^f	23.60 ^d
	200	38.60 ^g	23.40 ^e
Pawe- 03	0	41.10 ^{ab}	20.50 ^{gh}
	50	40.80 ^{bc}	20.20 ⁱ
	100	41.50 ^a	20.10 ⁱ
	150	41.10 ^{ab}	20.60 ^g
	200	41.10 ^{ab}	20.40 ^h
LSD(0.05)		0.60***	0.19***
SE±		0.21	0.06
CV (%)		0.91	0.51

Means without letter(s) in column per individual factors are not significantly different at $P = 0.05$, LSD - least significant difference, CV - coefficient of variation, SE - standard error, *** very highly significant at $P = 0.0001$, ** highly significant at $P = 0.01$, NS = non-significant difference at $P = 0.05$.

The oil content was determined gravimetrically after extraction using petroleum ether, in a Soxhlet instrument, technique (AOAC, 1990) expressed in dry matter in %.

2.5. Statistical analysis

Factorial analysis of variance for all collected data was performed following the procedure of Gomez and Gomez (1984), using the statistical analysis system computer software SAS 9.3 version (SAS Institute Inc, 2008). The normality of the data was tested by using the scatter plot technique. The treatments that showed significant differences was subjected to least significant difference (LSD) test for mean separation at 0.05 probability level. Furthermore, correlation analysis was made to determine the relationship between the agronomics and quality attributes of soybean. Regression analysis was used to determine the relationship of grain yield with other selected plant traits and oil content with protein content.

2.6. Economic analysis

Economic analysis was performed by using partial budget analysis following the procedures described by International Maize and Wheat

Improvement Center (CIMMYT, 1988). For the analysis, the average market prices of inputs from the months June to December (NPSZnB = 14.51 birr kg⁻¹ and urea = 14.25 birr kg⁻¹) and fertilizer application cost (400 birr ha⁻¹) were used and other costs were constant for all treatment. In addition, the average prices of grain (26 birr kg⁻¹) and stover yield (3 birr kg⁻¹) were collected during January, February and March, 2021. The mean grain and stover yield data were adjusted by deducting 10% of the actual yield (CIMMYT, 1988). All costs and benefits were calculated on hectare basis in Ethiopian Birr (ETB). Thus, total variable cost (TVC) was calculated as the sum of variable costs during sowing. Gross benefit (GB) was calculated as the sum of outputs. Net benefit (NB) was calculated by subtracting GB from TVC. After treatments were arranged in ascending order by TVC value, treatments with high NB and greater TVC than the preceding treatment were selected for further analysis; treatments with a lower NB value and a greater TVC than the preceding were excluded. Finally, marginal rate of return was calculated as change in net benefit divide by change in total variable cost times (Eq. (2)). A treatment having marginal rate of return greater than 100 % with the highest net benefit was considered to be economically best and it was recommended for farmers.

$$\text{MRR}(\%) = \frac{\text{NBt2} - \text{NBt1}}{\text{TVCt2} - \text{TVCt1}} \times 100 \quad (2)$$

where T2 and T1 are consecutive treatments (T) arranged in ascending order based on their TVC after excluding treatments with low NB and high TVC.

3. Results and discussion

3.1. Soil physical and chemical properties of experimental site before sowing

The soil laboratory results showed that the soil textural class of experimental site was clay loam as the particle size distribution of 35.64% sand, 28% clay and 36.36% silt (Table 1). This physical soil character has better abilities to hold plant nutrients and water (Ryan and Rashid, 2001). The soil pH of experimental site was 5.14 indicating that the soil chemical reaction was strongly acidic (Hazleton and Murphy, 2016). The study area of soil organic matter and organic carbon content were 3.42% and 1.99%, respectively. According to the ratings of Tekalign (1991) organic matter content was found to be medium while organic carbon content was found to be high (Ethio SIS, 2014). The experimental soil was low in total nitrogen (0.171 %) (Landon, 1991), sulfur (3.5 mg kg⁻¹), boron (0.45 mg kg⁻¹) and zinc (0.3 mg kg⁻¹) (Jones, 2019) contents, and very low in available phosphorus (1.4 mg kg⁻¹ of soil) (Olsen et al., 1954) and extractable potassium (0.12 Cmol (+) kg⁻¹) perhaps due to leaching caused by high rainfall (Figure 1).

3.2. Agronomic attributes of soybean

Plant height (PH) of soybean was varied significantly ($P < 0.01$) with blended fertilizer rates, but did not significantly influenced by varieties and the interaction of fertilizer rates with varieties (Table 3). Maximum (63.37 cm) plant height was observed with application of 200 kg ha⁻¹ NPSZnB while the shortest (48.23 cm) plant height was obtained with nil application of NPSZnB fertilizer. Increment of blended NPSZnB fertilizer rates resulted maximum vegetative plant growth due to higher availability of phosphorus, sulfur and nitrogen in the soil. This finding was in agreement with that of Okubay et al. (2014) who claimed that the highest soybean plant height (112.33 cm) was recorded from the application of the maximum rate (69 kg ha⁻¹N), while the lowest plant height was observed from the nil application of N fertilizer. It is also coincide with the research findings of Deresa et al. (2018) who found that increasing rates of blended NPS fertilizer (0–150 kg ha⁻¹) observed progressive increase in plant height of common bean (*Phaseolus vulgaris* L.).

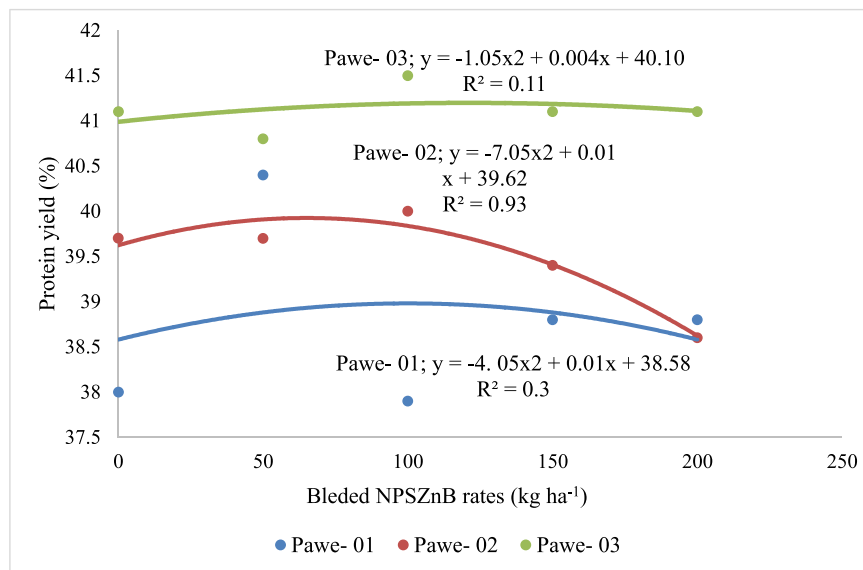


Figure 3. Polynomial regression analysis of soybean grain protein content as affected by NPSZnB fertilizer rates.

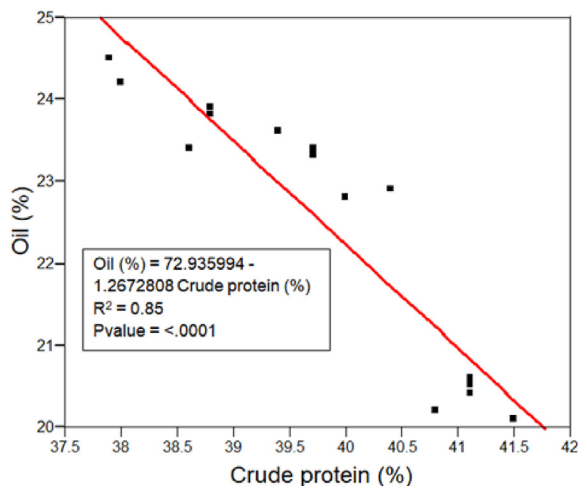


Figure 4. The relationship between grain oil content and protein content.

The main effects of varieties as well as the interaction effect of the varieties with blended NPSZnB fertilizer rates were not significantly affected the number of primary branches per plant (NPBPP) (Table 3). On the other hand, blended NPSZnB fertilizer rate was significantly ($P < 0.001$) affected the number of primary branches per plants. Maximum number of primary branches per plants (6.56) was recorded with application of 200 kg ha^{-1} NPSZnB fertilizer whereas minimum number of primary branches per plants (4.11) was obtained from nil NPSZnB fertilizer application. The number of primary branches per plant increased with increasing blended fertilizer application rates until optimum level reached. The increments in number of primary branches plant⁻¹ might be due to availability of phosphorous and boron for the activity of cell division, led to enhance plant height and lateral plant growth (Mesfin et al., 2007). This result is in line with Devi et al. (2012) who stated that the number of primary branches per plant was increased with the increased application of phosphorous and boron fertilizer rates.

The analysis of variance revealed that the main effect of varieties significantly ($P < 0.01$) affected soybean pod length (PL) (Table 3). However, there is no significant variation in pod length formed by utilizing blended NPSZnB fertilizer rates and the interaction effects of

varieties with NPSZnB rates (Table 3). Planting variety pawe- 02 gave the highest (3.47 cm) length of pods and planting the variety Pawe- 03 recorded the lowest (2.97 cm) pod length. Pod length varied with soybean varieties which might be due to genetic makeup of the plant. This result is in line with the findings of Shehu et al. (2010) who found that combined application of phosphorous and potassium fertilizers was not significantly affected sesame pod length. In conformity with this result, Jasemi et al. (2014) reported vegetative growth and biological yield has much dependence to consumption of chemical fertilizers, application of the fertilizers led to increasing biological yield.

The number of pods per plant (NPPP) was significantly ($P < 0.0001$) influenced by the main and interaction effect of NPSZnB fertilizer rates and varieties (Table 4). Planting variety Pawe- 03 with the application of 200 kg ha^{-1} NPSZnB fertilizer produced maximum (39.67) number of pods per plant, while the lowest (22.33) number of pods per plant was recorded when variety Pawe- 01 was planted with the nil application of blended fertilizer. This might be because of the presence of macro (N, P, and S) and micro-nutrients (viz. boron and zinc) in blended form which highly involved in pod initiation and formation in legume plants. This result is in line with findings of Khanam et al. (2016) who reported that the number of pods per plant of soybean was increased (51.14) with the increase in phosphorous and other micronutrient fertilizer rate. Similarly, it is also coincide with the findings of Xiang et al. (2012) who found that the increment of number of pods per plant of soybean is due to increasing amount of blended macro- and micro-nutrient fertilizer application from 0 to 112.5 kg ha^{-1} .

The result from statistical analysis revealed that the number of seeds per pod (NSPP) was significantly ($P < 0.05$) influenced by the effect of varieties, but not significantly affected by fertilizer rates and the interaction effect of NPSZnB rates with varieties (Table 4). Highest (2.8) number of seeds per pod was recorded from variety Pawe- 03, while the lowest (2) number of seeds per pod was produced in varieties Pawe- 02. This might be due to genetic constituents of the plant resulted in different number of seeds per pod. The result is disagreed with the research findings of Shubhashree (2007) who observed the number of seeds per pod of soybean was increased significantly due to increased rates of multi-nutrient blended fertilizers. This is also in line with the findings of Dame and Tasisa (2019) who reported blended NPS fertilizer had no significantly influenced the number of seeds per pod of soybean. According to the finding of Wondimu et al. (2016), the number of seeds per pod was not significantly affected by the main and interaction effects of soybean varieties and nitrogen rates.

Table 6. Correlation analysis of soybean agronomic attributes and quality parameters.

Variable	by Variable	Correlation	Signif Prob	Plot Corr.
PH	NPBPP	0.73	0.00	
PL	NPBPP	0.25	0.37	
PL	PH	0.14	0.62	
NPPP	NPBPP	0.65	0.01	
NPPP	PH	0.86	0.00	
NPPP	PL	0.01	0.98	
NSPP	NPBPP	0.33	0.23	
NSPP	PH	0.40	0.14	
NSPP	PL	-0.01	0.98	
NSPP	NPPP	0.47	0.08	
AGDBY	NPBPP	0.68	0.00	
AGDBY	PH	0.86	0.00	
AGDBY	PL	0.23	0.41	
AGDBY	NPPP	0.87	0.00	
AGDBY	NSPP	0.46	0.08	
HSW	NPBPP	-0.06	0.84	
HSW	PH	-0.18	0.53	
HSW	PL	0.75	0.00	
HSW	NPPP	-0.23	0.41	
HSW	NSPP	-0.44	0.10	
HSW	AGDBY	-0.18	0.53	
GY	NPBPP	0.45	0.09	
GY	PH	0.70	0.00	
GY	PL	0.04	0.88	
GY	NPPP	0.88	0.00	
GY	NSPP	0.53	0.04	
GY	AGDBY	0.83	0.00	
GY	HSW	-0.32	0.24	
HI	NPBPP	-0.19	0.51	
HI	PH	0.08	0.78	
HI	PL	-0.24	0.41	
HI	NPPP	0.41	0.14	
HI	NSPP	0.33	0.26	
HI	AGDBY	0.13	0.65	
HI	HSW	-0.33	0.25	
HI	GY	0.67	0.01	
PC	NPBPP	0.10	0.73	
PC	PH	0.24	0.39	
PC	PL	-0.47	0.08	
PC	NPPP	0.33	0.23	
PC	NSPP	0.44	0.10	
PC	AGDBY	0.34	0.22	
PC	HSW	-0.69	0.00	
PC	GY	0.48	0.07	
PC	HI	0.33	0.25	
OC	NPBPP	-0.04	0.88	
OC	PH	-0.27	0.33	
OC	PL	0.62	0.01	
OC	NPPP	-0.37	0.18	
OC	NSPP	-0.53	0.04	
OC	AGDBY	-0.36	0.18	
OC	HSW	0.86	0.00	
OC	GY	-0.53	0.04	
OC	HI	-0.43	0.12	
OC	PC	-0.92	0.00	

PH = plant height, NPBPP = number of branch per plant, NPPP = number of pods per plant, PL = pod length, NSPP = number of seed per pod, AGBY = above ground biomass yield, HSW = hundred seed weight, GY = grain yield, HI = harvest index, PC = Protein content and OC = oil content.

Above ground biomass yield (AGBY) of soybean was significantly ($P < 0.0001$) affected by the main and interaction effect of varieties and fertilizer rates (Table 4). Planting variety Pawe- 03 with the application of 200 kg ha^{-1} blended NPSZnB fertilizer rate gave the highest ($6944.44 \text{ kg ha}^{-1}$) above ground biomass yield, while the lowest biomass yield ($2874.60 \text{ kg ha}^{-1}$) was recorded when variety Pawe-01 was planted with nil application of fertilizer. Results also showed increasing trends of

biomass yield with the increase in rate of blended fertilizer rate (from 0 to 200 kg ha^{-1}). This might be due to sufficient availability of nitrogen in the soil significantly increased the vegetative part of the plant (plant height, number of primary branches, etc.) and this directly related to increments of production of above ground biomass yield. This result was in agreement with the findings of Dame and Tasisa (2019) who observed the maximum (8718 kg ha^{-1}) above ground dry biomass yield at the rate

Table 7. Results of partial budget analysis for effect of blended fertilizer rates on yield of soybean varieties at *Guangua* district, Northwestern Ethiopia in 2020.

Treatments (Variety + NPSZnB kg ha ⁻¹)	Gross benefit	Total variable cost	Net benefit	MRR%
Pawe- 01 + 0	29085.73	0.00	29085.73	
Pawe- 02 + 0	32460.65	0.00	32460.65	
Pawe- 03 + 0	39282.14	0.00	39282.14	
Pawe- 03 + 50	70410.78	1553.00	68857.78	1904.00
Pawe- 01 + 50	62517.88	1553.00	60964.88	
Pawe- 02 + 50	39060.64	1553.00	37507.64	
Pawe- 03 + 100	77232.06	2278.50	74953.56	5161.00
Pawe- 02 + 100	73789.44	2278.50	71510.94	
Pawe- 01 + 100	55160.69	2278.50	52882.19	
Pawe- 03 + 150	55157.93	3004.00	52153.93	
Pawe- 01 + 150	43660.80	3004.00	40656.80	
Pawe- 02 + 150	40667.79	3004.00	37663.79	
Pawe- 03 + 200	72553.64	3729.50	68824.14	4295.00
Pawe- 02 + 200	60517.84	3729.50	56788.34	
Pawe- 01 + 200	58374.98	3729.50	54645.48	

NPSZnB cost = 14.51 birr kg⁻¹, urea cost = 14.25 birr kg⁻¹ fertilizer application cost = 400 birr ha⁻¹, market price of soybean grain 26 birr kg⁻¹, market price of soybean stover = 3 birr kg⁻¹, adj. = adjusted grain and stover yield by 90 %, MRR = Marginal rate of return.

of 200 kg ha⁻¹ blended NPS fertilizer application and the minimum (6910 kg ha⁻¹) biomass yield was produced at nil NPS fertilizer application on soybean.

Soybean varieties, blended NPSZnB fertilizer rates and interaction of varieties with NPSZnB rates (Table 4) were significantly ($P < 0.0001$) affected the hundred seed weight (HSW). The heaviest (12.3 g) hundred seed weight was obtained when variety Pawe- 02 was planted with the application of 100 kg ha⁻¹ NPSZnB, while the lowest (7.33 g) hundred seed weight was recorded when variety Pawe- 03 was planted with the application of 200 kg ha⁻¹ NPSZnB fertilizer. This seed weight variation might be due to plant genetic constituents of varieties determine the size of grain and nutrient availability in the soil, in fact efficient utilization of nutrients (N, P, S, Zn and B) in a critical growth period of plants was improved at optimum level of blended NPSZnB fertilizer rate. Indeed, at optimum level of nitrogen nutrient in the soil enhances grain weights in crop plants and also grain sterility was reduced (Fageria Baligar, 2005). Phosphorous fertilized crop produced more pods per plant which were better filled with heavier seeds than control (Mfilinge et al., 2014). The present study was in line with the findings of Mandal et al. (2009) who reported the highest 100 seed weight of soybean was obtained at combined application of NPK fertilizer with farmyard manure than at nil application of NPK fertilizer. Similarly, in conformity with this result, Girma et al. (2014) observed significant increment in thousand seed weights of haricot bean at the rate of 40 kg ha⁻¹ NPS fertilizer application.

Seed yield is a primary concern of farmers (producers) to cultivate soybean crop. Different rates of blended NPSZnB fertilizer, varieties and interaction effect of NPSZnB rates and varieties had very highly significantly affected soybean grain yield (GY) (Table 4). Maximum soybean grain yield (2876.98 kg ha⁻¹) was produced when Pawe- 03 variety was planted with the application of 100 kg ha⁻¹ NPSZnB fertilizer, while the minimum grain production of soybean (1030.16 kg ha⁻¹) was recorded when Pawe- 01 variety was planted with nil application of fertilizer. It might be due to genetic makeup of the varieties and availability of nitrogen, phosphorus, sulfur, zinc and boron in soil after application in the form of blended fertilizer that increases plant growth and enhance seed yield, in which during photosynthesis assimilate partitioning of photosynthates from source to sink was properly performed. Regression analysis result showed that application of optimum blended fertilizer rate exponentially increased the grain yield of soybean, but when we apply above optimum level the yield has to be declined as indicated in (Figure 2). According to Sharma and Singh (2005) grain yield increment

was recorded due to sulfur fertilization; it maintains the critical balance of other essential nutrients in the crop plant and resulted in increased metabolic processes. This result is in agreement with the findings of Dame and Tasisa (2019) who showed maximum (2763 kg ha⁻¹) grain yield was produced at the rate of 100 kg ha⁻¹ NPS application and the lowest (1935 kg ha⁻¹) grain yield was recorded from the nil application of blended NPS fertilizer. Wondimu et al. (2016) reported that grain yield of soybean was significantly affected by main effect of soybean varieties and nitrogen fertilizer rates. Likewise, Habete and Buraka (2016) also observed the highest (2160 kg ha⁻¹) grain yield of Faba bean (*Vicia faba* L.) was observed from the application of the nitrogen fertilizer rate (23 kg ha⁻¹). Isah et al. (2014) also reported the regression analysis of two tomato (*Lycopersicon esculentum* Mill) varieties (Roma VF and UC82B) fruit yield showed a quadratic response to NPK fertilizer rate (0–450 kg ha⁻¹). Usman et al. (2020) reported that Blended (NPSB) fertilizer rates had significant effect on varieties Bread Wheat (*Triticum Aestivum* L.) varieties yield and yield component.

Varieties, NPSZnB rates and interaction of varieties with fertilizer rates significantly ($P < 0.0001$) affected the harvest index (HI) (Table 4). Planting of variety Pawe- 03 at 50 kg ha⁻¹ NPSZnB fertilizer rate recorded the highest (45.20%) harvest index and planting variety Pawe- 02 at 150 kg ha⁻¹ NPSZnB fertilizer rate gave the lowest (23.63%) harvest index. This might be due to optimum application of mainly N and S nutrients from the blended fertilizer that enhanced the partitioning of assimilates from different parts of plants to economical yield (grain yield). The present result is in line with the research findings of Malik et al. (2006) who reported the harvest index of soybean was significantly affected by the application of blended NPS fertilizer. Similarly, Wondimu et al. (2016) claimed that harvest index of soybean was highly significantly influenced by soybean varieties in which the maximum (47 %) harvest index was from variety Crow ford and minimum (32.7%) harvest index was from Awasa-95 which was significantly similar with variety Cocker-240 (36.7%).

3.3. Seed quality of soybean

Dwevedi and Kayastha (2011) stated that soybean crop was mostly cultivated due to occurrence of high protein content and type (8 essential amino acids). Varieties, NPSZnB fertilizer rates and interaction of varieties with fertilizer rates were highly significantly ($P < 0.01$) affected the protein content of soybean grain (Table 5). Planting variety Pawe- 03 at the rate of 100 kg ha⁻¹ NPSZnB fertilizer rate recorded the highest

(41.50%) protein concentration, while planting variety Pawe-01 at the nil application of blended fertilizer rate gave the lowest (38.00%) protein content. According to polynomial regression analysis, the variety Pawe-02 was strongly responded to blended fertilizer rates ($R^2 = 0.93$) as compared to the other two varieties (Figure 3). Thus, different soybean varieties with the different blended fertilizer rates contain different percentage of protein due to genetic variations present in plant and availability plant nutrient mainly N, S and B in the soil involved in the synthesis of amino acids which ultimately turned to protein. Indeed, optimum application of fertilizer having balanced plant nutrients increases the protein content of soybean grain, but an increment of fertilizer rates diminished the protein concentrations of the grain as explained by the regression analysis. These plant nutrients increase protein content of soybean through the synthesis of certain amino acids (cysteine and methionine). This result is coincide with the findings of Devi et al. (2012) who showed that the highest protein content of soybean grain was obtained due to supply of sulfur fertilizer (30 and 40 kg ha⁻¹) and the lowest protein content was recorded at nil application of sulfur fertilizer. Khaim et al. (2013) also reported that grain protein content of soybean was significantly influenced by nitrogen and sulfur containing chemical fertilizer in which maximum (45.73%) protein content was obtained at application of 55 kg ha⁻¹ N and 97 kg ha⁻¹ S whereas the lowest (40.12%) protein content was recorded at nil application of fertilizer. Likewise, Aytac et al. (2007) showed that the regression analysis of soybean grain protein content was a significant quadratic response to zinc fertilizer rates ($R^2 = 0.90$).

Results revealed that blended NPSZnB fertilizer rates, varieties and interaction effect were significantly ($P < 0.0001$) influenced the oil concentration of soybean grain (Table 5). In contrary Usman et al. (2020) reported grain protein content was affected by fertilizer rate and varieties, but the interaction between the two factors was non-significant. Elevated percentage (24.5%) of oil had been recorded when Pawe - 01 variety was planted with the application of 100 kg ha⁻¹ NPSZnB rate, while the lowest percentage (20.1%) of oil was recorded when Pawe - 03 variety was planted with application of 100 kg ha⁻¹ NPSZnB fertilizer rate. This might be due to the differences in genetic makeup of the soybean varieties and the finding also showed that NPSZnB fertilizer rates had negative impact on the oil content of soybean grain. Moreover, the variation in grain protein content of the varieties may be attributed to their variation in nutrient uptake and translocation capacities to the sink. Likewise, the protein concentration of the grain had also negative effect on oil concentration of the grain as indicated in (Figure 4). Similar to this finding Devi et al. (2012) indicated that the soybean grain oil content was significantly increase due to application of boron fertilizer. In contrary of this finding, Khaim et al. (2013) reported that oil content of soybean was not significantly influenced by the application of nitrogen and sulfur fertilizer. Usman et al. (2020) reported that Blended (NPSB) fertilizer rates had significant effect on varieties Bread Wheat (*Triticum Aestivum* L.) varieties quality parameters (Hectolitre weight and Grain protein).

3.4. Correlation analysis for studied traits

The simple linear correlation analysis indicated that, grain yield was significantly and positively correlated with harvest index ($r = 0.645^{***}$), biomass yield ($r = 0.826^{***}$), number of pod plant⁻¹ ($r = 0.851^{***}$) and plant height ($r = 0.535^{***}$), protein content ($r = 0.460^{**}$) and number of seeds pod⁻¹ ($r = 0.385^{**}$) and number of branches plant⁻¹ ($r = 0.297^*$). It was negatively correlated with oil content ($r = -0.525^{**}$) and 100 seed weight ($r = -0.321^*$) (Table 6). The number of pod plant⁻¹ was the main character which was highly positively influenced the grain yield. Significantly, increment of harvest index, biomass yield, number of pod plant⁻¹, plant height, protein content, number of seed pod⁻¹ and number of branches plant⁻¹ were increased grain yield simultaneously, but when oil content and 100 seed weight were increased grain yield was ultimately decreased. The present study is coincide with the finding of Abd El-Mohsen et al. (2013) who claimed that grain yield of soybean was

positively and significantly associated with number of branches plant⁻¹ ($r = 0.676^{**}$), number of pods plant⁻¹ ($r = 0.845^{**}$), number of seed plant⁻¹ ($r = 0.811^{**}$), seed yield plant⁻¹ ($r = 0.615^{**}$) and negatively associated with oil content ($r = 0.426^*$). Likewise, Painkra et al. (2018) reported that primary branches plant⁻¹ of soybean was positively correlated with number of pod bearing nodes ($r = 0.230^{**}$), number of seeds per pod ($r = 0.338^{**}$), protein content ($r = 0.280^{**}$), oil content ($r = 0.256^{**}$) and number of seeds per plant ($r = 0.142^*$).

3.5. Economic analysis

The result of the partial budget analysis revealed that the variety Pawe- 03 at the application of 100 kg ha⁻¹ followed by 50 kg ha⁻¹ NPSZnB resulted in maximum economic benefits of 74953.56 Birr ha⁻¹ (MRR = 5161%) and 68857.78 Birr ha⁻¹ (MRR = 1904%), respectively (Table 7). The highest marginal rate of return and net benefit in this treatment combination might be due to the highest grain and stover yield produced. However, the variety Pawe- 01 with nil application of blended NPSZnB fertilizer rates gave the lowest net benefit (29085.73 Birr ha⁻¹) (Table 7). This result is in agreement with that of Dame and Tasisa (2019) who reported the highest net benefit (21,457.2 birr ha⁻¹) from planting “dhidhessa” variety of soybean at the rate of 100 kgha⁻¹ blended NPS fertilizer application.

4. Conclusion

Among the three soybean varieties, planting variety Pawe- 03 with the application of 100 kg ha⁻¹ blended NPSZnB fertilizer rate gave the highest grain yield (2876.98 kg ha⁻¹), grain protein content (41.50%) and number of seed per pod (2.80). This variety also recorded maximum above ground biomass yield (6944.44 kg ha⁻¹) and number of pod per plant (39.67) with the application of 200 kg ha⁻¹ NPSZnB fertilizer rate, and highest harvest index at the rate of 50 kg NPSZnB ha⁻¹. The lowest grain yield (1030.16 kg ha⁻¹) was obtained when Pawe- 01 variety was sown with the nil application of fertilizer. According to partial budget analysis result, in the aspect of grain yield and quality; planting variety Pawe- 03 with the application of 100 kg ha⁻¹ NPSZnB fertilizer rate was found to be the best and economically feasible combinations with a net benefit of 74953.56 Birr ha⁻¹. In conclusion planting Pawe- 03 soybean variety with the application of 100 kg ha⁻¹ NPSZnB fertilizer rate would be recommended for most Northwestern agro ecological areas of Ethiopia. It is suggested that this experiment should be repeated in various agro ecologies with various soybean varieties.

Declarations

Author contribution statement

Asmachew Agegn; Yayeh Bitew: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dereje Ayalew: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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