Effect of Fertilizer Blends on Yield and Yield Components of Tef (*Eragrostis tef* [Zucc. Trotter]) on Vertisols of Becho District in the Central Highlands of Ethiopia

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Abstract

After the nation-wide study of EthioSIS which discovered the deficiency of nutrients such as Iron (Fe), Zinc (Zn), Boron (B), Sulphur (S) and Potassium (K), fertilizer recommendation in Ethiopia switched to zinc, boron and the zinc-boron blends. Nevertheless, there were no specifications for soil and crop types in this latest fertilizer recommendation. To address this, Capacity Building for Scaling up of Evidence-based Best Practices in Agricultural Production in Ethiopia (CASCAPE) had been conducting farm trials on blend types and rates on various crops and soil types in various parts of the country; among which tef in Vertisols is one of the trials conducted in central highlands of Ethiopia. The trial was conducted in two cropping seasons (2017 and 2018). In the first trial season, there were eight treatments (five levels of NPSZnB, Di-ammonium Phosphate (DAP), NPS and QUEFTS) whereas in the second, one treatment from the previous year (DAP) was dropped and two new ones (NPSKB and NPSKZn) were added. The experimental layout was randomized complete block with three replications. Soil sample, agronomic and economic data were collected following standard procedures. In 2017, the yield benefit of the different rates of NPSZnB blend did not significantly differ from that of 150 $kgha^{-1}$ DAP and 100 $kgha^{-1}$ NPS, which, in order of time, were the blanket recommendations before the introduction of micronutrient containing fertilizer blends. In 2018, grain yield for 300 NPSZnB $kgha^{-1}$ was significantly higher than 100 NPS. Moreover, both of the K-containing treatments, 300 NPKSB $kgha^{-1}$ and 300 NPKSZn $kgha^{-1}$ exhibited higher yield than the maximum rate of NPSZnB. The combined over years analysis revealed insignificant yield variation between most rates of NPSZnB, and only 300 NPSZnB $kgha^{-1}$ was found to be significantly higher than 100 NPS $kgha^{-1}$. In light of Pearson correlation coefficients, there was a positive and significant correlation between grain and straw yield with available P and Mn. In contrast, there was a negative and significant correlation between grain and straw yield with K and OM. However, the correlation of micronutrients Zn and B with grain and straw yield were insignificant. The marginal rate of return (MRR%) of all the three high rates, 300 NPSZnB $kgha^{-1}$, 300 NPSKB $kgha^{-1}$ and 300 NPSKZn $kgha^{-1}$, were above the minimum acceptable rate of return (MARR) of 100%. Regardless of their actual

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nutrient composition, the insignificant but lower yield of the respective equivalent rates of the blend with NPS (100 kgha^{-1}) and DAP (150 kgha^{-1}) raises a question on the worth of adding Zn and B at the expense of N and P. If and when their importance in the formulation is conclusive, the current study suggests for the substantial raising of the rate as only the maximum rate increased yield significantly. Considering the addition of K and reducing N and P from NPS greater than the addition of B and Zn, irrespective of how much to add, the highest yield by NPSKB and NPSKZn suggests the merit of K in the blend.

Keywords: Blended fertilizers, Vertisol, *Tef*, CASCAPE, Becho, Central highlands, Ethiopia

1. Introduction

Agriculture is the mainstay of the majority of the Ethiopia population and the main driving force for the country's economy. The sector accounts for 43% of GDP, 90% of exports and 85% of all employment (FAO, 2011). Crop production takes the highest portion of the farming sector; cereals, pulses, and oilseeds covering up to 80.71%, 12.61% and 6.68 %, respectively, of the cultivated land in the 2018 Meher cropping season (CSA, 2018). Among cereals, tef stood first in terms of percentage area coverage, which is 23.85 % (CSA, 2018). However, relative to the potential yield of the crop, the productivity of the crop is as low as 1.74 tha^{-1} (CSA, 2018). From the extensive list of production constraints, low availability of nutrients is thought to be a significant limiting factor, mainly due to soil erosion, unbalanced nutrient supply, low organic matter input and absence of nutrient cycling (Tekalign *et al.,* 2001).

Considering the fact that soil fertility is one of the biggest challenges in the farming sector, the government of Ethiopia (GoE) has been pushing to increase fertilizer application along with good agronomic practices. As a result, the national annual fertilizer use grew from 3,500 tons in the early 1970s to about 140,000 tons by the early 1990s and reached about 200,000; 400,000; 550,000; 1,000,000 tons in 1994, 2005, 2010, and 2015, respectively (Rashid *et al.,* 2013; Eyasu *et al.,* 2019). Despite the significant leap in fertilizer import over the years, the national average fertilizer application rate remains low. The application dominantly stands at 43 kg/ha Urea (46 % N) and 65 kg/ha DAP (Di-ammonium phosphate: 18% N, 46% P_2O_5). These fertilizers together supply 32 kg N and 30 kg P_2O_5 /ha, which is far below the blanket recommendation (100 kg urea and 150 kg DAP/ha, together supplies 73 kg N and 69 kg P_2O_5/ha) (Eyasu, 2016; Eyasu, 2017; Lulseged *et al.*, 2017a). In addition to the low level of fertilizer use, the ongoing trend of adopting the blanket and unbalanced application of nutrients, irrespective of soil and crop types, crop varieties and agro-ecological zones, is resulting in wide gap between the potential and the actual crop yields and is creating farm nutrient imbalances (Hailu *et al.,*1991*;* Workneh and Mwangi,1992; Nandwa and Bekunda,1998*;* Abay and Mulugeta, 2017).

The macronutrient depletion rate of Ethiopian soils for the year 2000 was forecasted to have been -122 kg N, -13 kg P and -82 kg K/ha (Stoorvogel *et al*., 1993). In the past, nitrogen (N) and phosphorus (P) were thought to be deficient in Vertisols of Ethiopia (Tekalign *et al*., 2001). Nonetheless, recent studies unveiled that all micronutrients and most macronutrients were depleting and their deficiency symptoms started to appear in major crops and growing regions of the country (Asgelil *et al*., 2007; Wassie and Shiferaw 2011; Lulseged *et al*., 2017b). Likewise, the recent national soil fertility mapping initiative (Ethiopian soil information system /EthioSIS/) led by the Ethiopian agricultural transformation agency (ATA) revealed the deficiency of nutrients such as Fe, Zn, B, S and K (EthioSIS, 2015). This result is believed to have served as a waking call for the Ethiopian government to adopt a balanced nutrient recommendation. Subsequently, using the EthioSIS soil fertility atlas of 2015 as a reference, kebele level blend fertilizer recommendations were made for the four main regions of the country, Amhara, Oromia, SNNPR and Tigray. To that end, two blend formulas were formulated using NPS as base fertilizer, namely, zinc blend (14% N, 23% P_2O_5, 8.2% S, and 1.2% Zn) and zinc-boron blend (14% N, 21% P_2O_5, 15% K_2O, 6.5% S, 1.3% Zn and 0.5% B) (Karltun *et al*., 2013). Five blending plants were established to be operated by selected cooperative unions, namely, Enderta (Tigray), Merkeb (Amhara), Becho Woliso (Central Oromiya) and Nekemt (West Oromiya).

Even if the change from blanket rates at the national level to kebele level is a substantial transformation to the sector, the recommendations of the blend formulations still remained blanket. There was no specification for different crop and soil types. In addition, the recommendations do not provide clear advice on how much blend to use; if the amount is indicated it has never been validated in field research. Therefore, since the past few years, CASCAPE has been undertaking numerous on-farm trials in most parts of the country on different soil and crop types. Among these, blended fertilizer trial on tef in Vertisols of Becho District was one of the experiments undertaken by the project. The objectives of the trial were to evaluate the efficacy of blended fertilizer (BF) rates on yield attributes of tef (*Eragrostis tef*) in Vertisols of central Ethiopia; to identify economically feasible BF rate; and to weigh the relationship between soil parameters and *tef* yield. This paper reports results of the trial regarding the efficacy of BF rates on yield attributes of tef in Vertisols, economically feasible BF rate, and the relationship between soil parameters and *tef* yield.

2. The Study Sites and Methods

2.1. Study Area Description

Becho is a district located in the central part of the country under South West Shewa Zone of Oromia Region. It is divided into 21 *Kebeles* (the lowest administrative units in Ethiopia composed of one or more villages) and two towns. Tulu Bolo, the Woreda capital town, is found 80 kms away in the west of Addis Ababa, the capital city of the country. Geographically, the woreda lies between 8°34'59.99" N and 38°14'60.00" E. The Woreda has an altitude ranging from 1850 to 2200 m.a.s.l. The woreda experiences mean annual rainfall of about 1300 mm; with a unimodal rainfall pattern in which the main rainy season runs from May to September. The mean annual temperature ranges between 16^0C to 25^0C. The land is moderately fertile and Vertisol dominates the soil of the woreda. The topography is generally plain with undulating and hilly land. Mixed farming (crop and livestock production) is the dominant livelihood of the rural residents. The major crops produced in the woreda are tef, wheat, and chickpea. Tef and wheat are grown from July to November whereas chickpea is grown September - December.

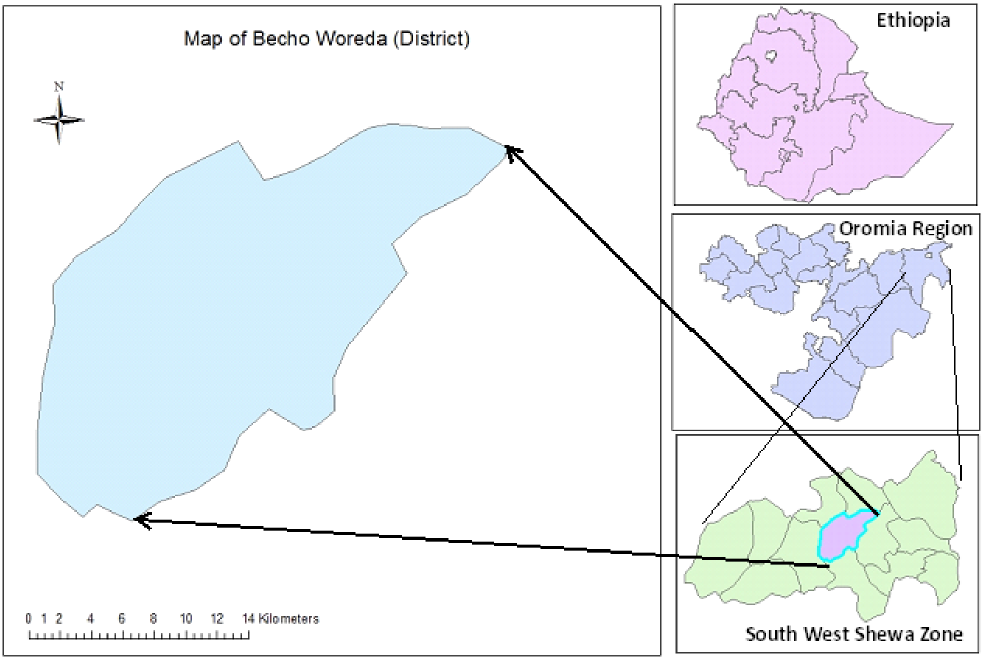

Figure 1: Map of Becho Woreda (District)

2.2. Site Selection, Treatments, Agronomic Management and Design

Due to the fact that Vertisol is one of the dominant soils in Ethiopia and tef is mostly cultivated in this soil, Becho woreda was selected for the experimental study since it fulfills the two conditions; dominance in Vertisol and tef cultivation in the soil type. Accordingly, Vertisol farms were selected as experimental sites based on soil classification system of FAO (1994). The farmer's standard land preparation and planting method for tef, i.e., plowing three times before and once at planting and broadcasting 15 kg/ha seed, were followed. The experimental design was randomized complete block with three replications; farmers' fields were used as replication on 10x5 m plot for each treatment. *Kuncho* tef variety (Dz-Cr-387) was used as a test crop in both years of the experimental period. Apart from DAP (Diammonium phosphate; $18N\text{-}38P_2O_5\text{-}2.3S$) and NPS ($19N\text{-}38P_2O_5\text{-}7S$), the recently adopted fertilizer blends, namely, NPSZnB ($17N\text{-}34P_2O_5\text{-}6.5S\text{-}2.2Zn\text{-}0.6B$), NPKSB ($13.7N\text{-}27.4P_2O_5\text{-}13.74k_2O\text{-}5.1S\text{-}2.2Zn$), and NPKSZn ($13.7N\text{-}27.4P_20_5\text{-}14.4k_2O\text{-}5.98S\text{-}2.2Zn$) were considered for studying and field experiments were conducted in 2017 and 2018 cropping seasons. The treatments with the respective actual nutrient composition are specified in Table 1 below. Treatment combination T1-T8 had been part of the 2017 experimentation. In 2018, due to unavailability of DAP, T7 was not part of study, whereas T9 and T10 were added to evaluate NPKSB and NPKSZn blends. T8 is the QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) model generated rate (Smalling and Janssen, 1993). It predicts nutrient uptake and yields from chemical soil fertility indices. All phosphorous-containing blends were applied once at planting, whereas urea was applied two times; half at planting and half at tillage stage of the crop. All the recommended agronomic management practices for tef were followed.

Table 1. Fertilizer rate and actual nutrient composition (kgha^{-1})

Treatments	**Fertilizer application level** (kgha^{-1})	**Actual nutrient content** (kgha^{-1})					
		N	**P**	**S**	**Zn**	**B**	**K**
T1	50NPSZnB +100 Urea	55.0	7.4	3.5	1.1	0.4	0.0
T2	100NPSZnB +100 Urea	63.0	15.0	7.0	2.2	0.7	0.0
T3	150NPSZnB +100 Urea	72.0	22.0	11.0	3.3	1.1	0.0
T4	200NPSZnB +100 Urea	80.0	30.0	14.0	4.4	1.4	0.0
T5	300NPSZnB +100 Urea	97.0	44.0	21.0	6.6	2.1	0.0
T6	100 NPS +100 Urea	65.0	17.0	7.0	0.0	0.0	0.0
T7	150 DAP +100 Urea	73.00	30.0	2.3	0.0	0.0	0.0
T8	QUEFTS	54.0	12.3	5.2	0.0	0.0	0.0
T9	300NPSKB+100 Urea	87.1	35.9	15.3	0.0	1.6	35.9
T10	300 NPKSZn+100 Urea	87.1	35.9	18.0	6.6	0.0	36.4

2.3. Soil Sampling and Laboratory Procedures

Composite soil samples were collected from each experimental unit after harvest. Samples were taken from five cross-sectional areas of the plot with an augur depth of 0-30 cm. An equal volume of the auger dug soil from each area of the plot were mixed to make the composite for each plot. Lab analysis was done by Horticoop soil fertility lab, located on the outskirts of Debre Zeit town, Ethiopia. The determined soil parameters were: soil acidity (soil pH-H_2O), organic carbon (OC), organic matter (OM), total nitrogen (TN), cation exchange capacity (CEC), available phosphorus (AP), Calcium (Ca), Potassium (K), Sodium (Na), Sulphur (S), Magnesium (Mg), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn) and Boron (B). Soil samples were analyzed following standard procedures as described in Van Reeuwijk

(2006). The pH-H_2O was measured using 1:2.5 soil to solution suspension using a pH meter. The Walkley and Black method was applied to determine the OC content while TN was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). The AP (Olsen) was measured using a sodium bicarbonate extraction solution. Exchangeable cations and CEC were determined by the Ammonium Acetate method using an Atomic Absorption. A spectrophotometer was used for exchangeable $Ca^{2+}$and Mg^{2+} and flame photometer was used for Na^{+} and K^{+} determination. The DTPA extraction method was used for available micronutrients, Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn) and Boron (B) (Tan, 1996).

2.4. Data Collected and Measurements

Agronomic measurements on plant height (cm), panicle length (cm), days to 50% maturity, biomass yield (kgha^{-1}) and grain yield (kgha^{-1}) had been made. Plant height was measured at physiological maturity from the ground to the tip of the panicle from ten randomly selected plants from each plot. Panicle length was measured as the length of the panicle from the node for ten randomly selected plants. Both plant height and panicle length were measured at harvest using a measuring tape. Days to 50% maturity was taken as the number of days from planting to 50% of plants in the plot physiologically matured. Biomass and grain yield were taken using a 0.5m^2 quadrant from 2m^2 area. After threshing, grain yield was measured using an electronic balance. Biomass and grain yield were converted to yield/ha. The straw yield was calculated by subtracting grain yield from biomass yield. The harvest index was calculated by dividing grain yield by biomass yield. Soil sampling and analysis were made following standard procedures described above. Following the procedure of CIMMIYT (1988) partial budget analysis, prices of each fertilizer blend, field value of tef grain and straw were collected.

2.5. Statistical and Economic Analysis

Analysis of variance (ANOVA) was carried out independently for each season and parameter and the Duncan multiple range test (DMRT) of mean separation was employed in case of a significant difference between treatment effects at $P<0.05$. Homogeneity of error variance was checked using Bartlett chi-square test before making the analysis of variance for the over year's treatment effect. The Pearson correlation test was carried out to determine the relationship between soil parameters and grain and straw yield of the crop. The SAS statistical software university edition, SAS 9.4m6 (2018), was used for all statistical procedures.

Economic analysis was done according to the CIMMIYT (1988) partial budget analysis technique. Partial budgeting is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. It considers variable input costs and the field prices of the produce between treatments. In our case, except for the cost of fertilizer, the cost of other inputs, including seed and labor costs, were uniform or insignificant between treatments. Therefore, the cost associated with the type of the fertilizer blend and the difference in the rate of application determined the total variable cost (TVC). The field price of tef grain and straw were used to compute gross field benefits (GB), and hence, the change in average grain and straw yield and the difference in the cost of fertilizer across treatments were the factors that determined the net benefit (NB) and the marginal rate of return (MRR). To compensate for the possible inflated estimation of average grain and straw yield, mainly because of the cautious application of inputs and the small plot effect, the mean grain and straw yields were adjusted downwards by 10%. Gross field benefit (GB) was calculated as average adjusted grain and straw yield (kgha^{-1}) multiplied by field price of the tef grain and straw. Total variable cost (TVC) was calculated as the sum of all costs that were variable across treatments, in this case, the cost of fertilizer equated TVC. The net benefit (NB) per hectare for each treatment was the difference between the gross benefit and the total variable cost. The marginal rate of return (MRR) was calculated between non- dominated (D) treatments. Any treatment that has a net benefit which is less than or equal to a net benefit that can be obtained with a lower-cost treatment is considered dominated and left out of the marginal rate of return (MRR) calculation. The marginal rate of return for each non-dominated treatment was calculated by using the following formula:

$$\mathrm{MRR} = \Delta\,\mathrm{NB} * 100/\Delta\,\mathrm{TVC}$$

Where: MRR is marginal rate of return in percentage; ΔNB is change in net benefit; and ΔTVC stands for change in total variable cost. Upon arranging treatments in ascending order of TVC, the minimum acceptable rate of return (MARR) of 100 % was employed to select the economically feasible treatment (CIMMIYT, 1988).

2.6. Limitations of the Study

Although the research proposal was developed centrally by senior soil researchers, there was no ‘0 rate’ (control rate); and because of budget limitation, laboratory analysis for the before-planting soil, grain and plant tissue had not been carried out. This made it impossible to calculate the common measures of nutrient use efficiency such as agronomic efficiency, apparent recovery efficiency, and physiological efficiency. In addition, treatments were not consistent over the years so that it was not possible to see the over-season effect of all treatments; as also because the data presented for some treatments were single-year data. Furthermore, the over-years inconsistency of the treatments may have to do with the recent introduction of fertilizer blends to the farming system, on which there were only a handful of published studies. Consequently, it was not possible to make any reasonable comparisons.

3. Results and Discussion

3.1 Soil Physicochemical Properties after Harvest

The effect of the different BF rates on the chemical properties of the soil is described in Table 2 below. Except for Boron, at $p< 0.05$, there was no statistically significant difference between BF rates on the measured soil physicochemical parameters. Soil pH ranged from 6.74 to 7.19, which fell under the neutral pH range; an optimal range for the availability of essential crop nutrients (Brady, 1990; Liu *et al.,* 2014*;* 2006; Abebe, 2007). Cation exchange capacity (CEC) of BF rates was in very close proximity, the highest and the lowest being 49.69 cmol/kg and 47.24 cmol/kg, respectively, which, according to Landon (1991), was considered as very high, and, thus, favorable for crop growth. Moreover, soil with CEC higher than 20 cmol (+) Kg^{-1} is generally considered as one with very strong nutrient retention ability (Liu *et al.,* 2014). Organic matter (OM), organic carbon (OC) and the carbon-to-nitrogen ratio between BF rates were not significantly different. Nevertheless, the % OC and % OM of all treatment means were in the low range (Troeh and Thompson, 2005; Liu *et al.,* 2014). This was because the result was from the after-harvest soil, and the low organic matter addition and substantial removal of crop biomass from the arable lands in Ethiopia (Yihenew, 2002). The C:N (carbon-to-nitrogen ratio) of 9.97% to 13.04% even for the after harvest soil, were between the normal range for cultivated tropical soils (Landon, 1991; Hazelton and Murphy, 2007).

The mean TN (total nitrogen) and AP (available phosphorus) between BF rates were almost the same. TN was between 0.06 and 0.09, which according to Takalign *et al*. (1991) is classified as soil with poor nitrogen content. This was due to the crop nutrient use and low addition of organic matter to the soil (Yihenew, 2002) and leaching (Lin *et al*., 2001). The amount of AP varied between 6.46 and 15.93 Mg Kg^{-1}, which, according to Horneck et al., (2011), was within low to medium range. It is in agreement with the studies by Tekalign and Haque, (1991), Tamrat (1992), and Yihenew (2002). Even though the data was from the after-harvest soil, as reported by many authors (Murphy, 1968; Tekalign et al., 2002; Abebe and Endalkachew, 2012), the availability of phosphorus under most soils of Ethiopia was on the decline, largely by the impacts of fixation, abundant crop harvest and erosion. The addition of K (Potassium)-containing blend, NPKSB, and NPKSZn did not seem to significantly affect the amount of K in the after-harvest soil. Treatments, with no K in them, exhibited identical amounts of phosphorous with those containing K (Table 2). K ranged from 1.29 to 1.36 cmol (+) Kg^{-1}, which, according to Hillette *et al.* (2015), was in a very wide range and it was in agreement with previous findings by Beyene (1982), Kamara *et al*. (1989), and Lemma and Smit (2008). S (Sulphur) content was between 6.48 and 7.46 Mg Kg^{-1}, which, even after crop harvest, was above the critical level, which is 5 Mg Kg^{-1} (Lewis, 1999).

Micronutrients such as Fe (Iron), Mn (Manganese) and Zn (Zinc) were not different between treatments. After crop nutrient use, Fe and Mn were well above the critical level established by Soltanpour (1985) and Jones (2003), which was 5 Mg Kg^{-1} for Fe and 1 Mg Kg^{-1} for Mn. The result was similar to the findings of Fisseha (1992) who reported the adequate amount of Fe and Mn in Ethiopian Vertisols. Nevertheless, except for the treatment with 300NPKSZn +100 Urea kgha^{-1}(1.42 mg Kg^{-1}), Zn was below the critical level established by Soltanpour (1985) and Jones (2003), which is 1.5 mg Kg^{-1}. As Zinc is generally considered deficient in most Ethiopian soils (Ethiosis, 2015; Eyob *et al*.,2016; Ashenafi *et al*., 2016), and in the central highlands of the country (Hillette *et al.*, 2015) where this study area is located, it is understandable that the soil after-harvest exhibited Zn deficiency. Boron (B) was significantly different between treatments ($p<0.05$) and it varied between 0.35 to 2.57 Mg Kg^{-1}, which, according to Horneck *et al.* (2011), was between low to excessive. The highest Boron amount was recorded in treatment with 300NPKSB +100 kgha^{-1}. Although there was a treatment with equal amount of B as NPKSB blend (Table 1), we found it very difficult to explain the very excessive amount of B in the soil where NPKSB was applied. The result was consistent across replications as well.

Table 2. Means for selected soil properties after harvest, 2018

	Soil Physicochemical Properties												
	PH	**K**	**CEC**	**AP**	**S**	**B**	**Fe**	**Mn**	**Zn**	**OC**	**OM**	**TN**	**C:N**
BF rate (Kgha^{-1})		(cmol (+) Kg^{-1})				(Mg Kg^{-1})					(%)		
50 NPSZnB+100 Urea	6.74	1.29	48.04	6.46	6.48	0.40^{b}	21.22	8.06	0.82	0.80	1.39	0.06	12.64
100 NPSZnB+100Urea	7.15	1.36	49.69	8.96	6.66	0.49^{b}	21.02	7.89	0.47	0.84	1.46	0.06	13.21
150 NPSZnB+100 Urea	7.19	1.30	47.25	9.48	6.54	0.41^{b}	22.95	10.44	0.61	0.89	1.54	0.07	13.02
200 NPSZnB+100 Urea	7.12	1.33	47.33	8.12	6.84	0.41^{b}	19.70	9.15	0.75	0.78	1.35	0.07	11.36
300 NPSZnB+100 Urea	7.13	1.32	47.55	14.01	7.46	0.40^{b}	21.80	9.29	1.42	0.92	1.59	0.07	13.64
100 NPS+100 Urea	7.16	1.31	47.24	10.04	7.13	0.35^{b}	21.01	8.81	0.42	0.83	1.44	0.06	13.06
QUEFTS	7.15	1.31	47.68	8.08	6.91	0.57^{b}	21.01	7.18	0.37	0.85	1.47	0.08	11.26
300 NPKSB +100 Urea	7.06	1.30	48.67	9.48	6.69	2.57^{a}	22.62	8.92	0.32	0.86	1.49	0.09	9.79
300 NPKSZn +100 Urea	7.09	1.33	48.82	15.93	7.10	0.37^{b}	22.24	9.04	2.51	0.85	1.48	0.06	13.64
Mean	7.09	1.32	47.68	10.09	6.87	0.59	21.28	8.79	1.01	0.85	1.47	0.07	12.47
CV (%)	4.04	4.36	4.79	50.73	6.77	59.97	69.90	27.80	120.0	8.50	8.50	21.4	15.04
SEM	0.05	0.01	0.44	0.98	0.09	0.07	0.49	0.47	0.28	0.01	0.02	0.00	0.36
R^{2}	0.35	0.74	0.56	0.50	0.51	0.52	0.69	0.44	0.33	0.38	0.38	0.45	0.42
Sig (*P <0.05*)	*ns*	*ns*	*ns*	*ns*	*ns*	**	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Notes: 1) **PH**: potential Hydrogen; **Ca:** Calcium; **K:** Potassium; **CEC**: cation exchange capacity; **AP**: available Phosphorous; **S**: Sulphur; **B**: Boron; **Fe**: Iron; **Mn**: Manganous; **Zn**: Zinc; **OC**: organic Carbon; **OM**: organic matter; **TN**: total nitrogen; **C:N**: Carbon to Nitrogen ratio; **cmol (+) Kg-1**: centimoles of positive charge per kilogram of soil; **Mg Kg-1**: milligram per kilogram of soil; **CV**: Coefficient of variation; **SEM**: Standard error of the mean, **R^{2}**: Coefficient of determination

2) **Sig**: * symbolizes significance at P>0.01 but less than 0.05;

3) Means within a column followed by the same letter are not significantly different from each other.

3.2. Effect of BF on Yield and Yield Components of *Tef*

In the 2017 trial, analysis of variance at P<0.05 revealed almost no difference between treatments for all parameters except for plant height (PH) (Table 3). The grain yield of 300 NPSZnB +100 kgha^{-1} Urea was only 100 kg higher than the next high yielding treatment, 150 NPSZnB +100 kgha^{-1} Urea. The treatment with a higher rate of the blend resulted in significant increase only in plant height. ANOVA for the 2018 trial, on the other hand, revealed that all parameters, except panicle length (PL), were significantly different between fertilizer rates (Table 3). Significantly higher grain yield was recorded for K-containing treatments. The highest for 300 NPKSB +100 kgha^{-1} Urea, followed by 300 NPKSZn +100 kgha^{-1} Urea. Comparing the amount of N and P reduction from what would be in NPS by the different blending formulations, adding B, Zn and K into to NPS, the N and P depressing influence of adding K into NPS was greater than adding Zn and B. For instance, 300 NPSZnB +100 kgha^{-1} urea in T5 had 97 N and 44 P, whereas the equivalent K-containing rate 300 NPKSB +100 urea kgha^{-1} in T9 contains 87.1 and 35.9 P (Table 1). Nevertheless, with considerably lower N and P, the K containing blend recorded higher grain yield. This was similar to other studies which reported the significance of K on tef productivity (Feyera *et al.*, 2014; Gashu, 2017) and the positive effect of supplementing NPS with K on tef yield (Yohannes *et al.,* 2019). Prior studies on potato reported significant increase in yield following the application of K (Wassie *et al.* 2009; Gizaw *et al.* 2010).

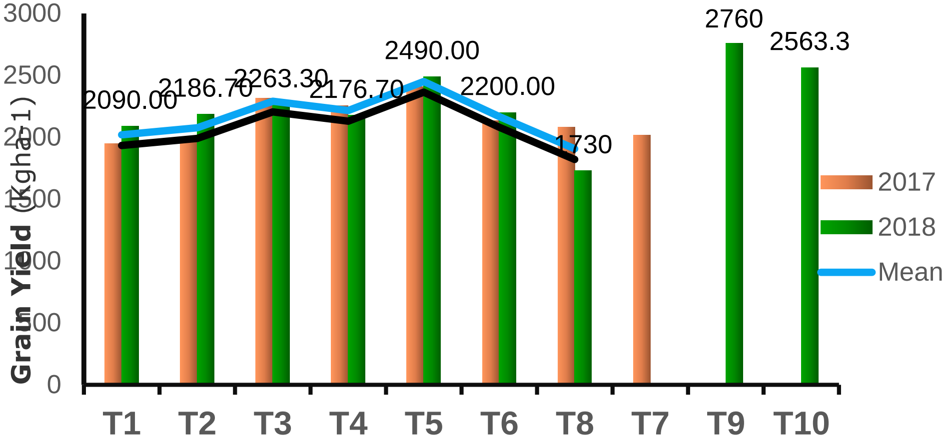

Figure 2. Mean grain yield (kgha^{-1}) for all treatments of the two-year experimental period**;** data for T7, T9 and T10 are one-year data (see **Table 1** for treatment description)

Consistent to the previous study year (2017), 300 NPSZnB +100 kgha^{-1} was the high yielding non-K containing treatment in 2018. In 2017, the yield benefit of the different rates of NPSZnB blend did not significantly differ with 150 kgha^{-1} DAP and 100 kgha^{-1} NPS, which were the blanket recommendations before the introduction of micronutrient containing fertilizer blends. In 2018, from the NPSZnB blend, 300 kgha^{-1} was the only rate significantly differing with 100 kgha^{-1} NPS. Moreover, the mean grain yield for most rates of NPSZnB was not significantly different from each other.

The combined over years analysis of variance is presented in Table 4. It shows a significant difference for all measured parameters except for DM (days to 50% maturity). Grain yield for 300 NPSZnB +100 Urea kgha^{-1} is the highest with 2450.00 kgha^{-1}, and is significantly higher than the former blanket recommendation 100 NPS +100 kgha^{-1}; bearing in mind the substantial rate difference between the two. Grain yield of 100 NPS +100 kgha^{-1} urea was higher than 100 NPSZnB+100 kgha^{-1} urea. This might have to do with the change in N and P amount between the two treatments. 100 NPS + 100kgha^{-1} urea in T6 has 65 and 17 kg of N and P respectively, whereas 100 NPSZnB+100 kgha^{-1} urea in T2 has 63 and 15 kg of N and P, respectively. The same was true in the case of 150 kg DAP and 150 Kg NPSZnB in 2017. The difference between DAP and blend fertilizer was particularly large for P; from 73 and 30 kg N and P in DAP in T7 to 72 and 22 kg N and P in NPSZnB in T3 (also see Table 1).

Table 3. Mean for yield and yield components of tef, 2017 and 2018 trials

Year	**BF rate** (kgha^{-1})	**BM**	**GY**	**PH**	**PL**	**DM**	**StY**	**HI**
2017	50 NPSZnB +100 Urea	9000.00	1950.00	101.33^{bc}	34.33	115.66	7050.00	0.25
	100 NPSZnB +100 Urea	8667.00	1966.70	104.00^{bc}	35.00	110.33	6700.00	0.26
	150 NPSZnB +100 Urea	11667.00	2316.70	110.33^{ab}	36.66	113.66	9350.00	0.20
	200 NPSZnB +100 Urea	10000.00	2253.30	111.33^{ab}	37.66	114.33	7747.00	0.24
	300 NPSZnB +100 Urea	12333.00	2410.00	115.67^{a}	38.00	112.33	9923.00	0.19
	100 NPS +100 Urea	12000.00	2133.30	109.33^{abc}	35.33	113.66	9867.00	0.18
	150 DAP + 100 Urea	9333.00	2016.70	106.33^{abc}	28.33	113.67	7317.00	0.26
	QUEFTS	8000.00	2083.30	99.33^{c}	34.67	113.33	59.17	0.28
	Mean	10125.00	2141.25	107.20	35.00	113.67	7985.75	0.23
	CV (%)	25.23	9.95	5.12	11.09	3.85	30.90	25.65
	SEM	521.61	43.51	1.12	0.79	0.89	503.71	0.01
	R^2	0.59	0.59	0.94	0.82	0.29	0.58	0.62
	Sig ($P < 0.05$)	ns	ns	*	ns	ns	ns	ns
2018	50 NPSZnB +100 Urea	7666.70^{de}	2090.00^{bc}	111.13^{bc}	36.30	117.00^{ab}	5576.70^{dc}	0.28
	100 NPSZnB +100 Urea	9000.00^{dc}	2186.70^{bc}	110.80^{bc}	37.67	119.67^{ab}	6813.30^{bc}	0.24
	150 NPSZnB +100 Urea	9000.00^{dc}	2263.30^{ab}	116.67^{ab}	40.83	117.00^{b}	6736.70^{bc}	0.26
	200 NPSZnB +100 Urea	10000.00^{abc}	2176.70^{bc}	118.33^{ab}	39.73	119.00^{ab}	7823.30^{ab}	0.22
	300 NPSZnB +100 Urea	11000.00^{ab}	2490.00^{ab}	127.60^{a}	38.90	121.00^{ab}	8510.00^{ab}	0.23
	100 NPS +100 Urea	9333.33^{bcd}	2200.00^{bc}	111.00^{bc}	39.53	118.33^{ab}	7133.30^{bc}	0.24
	QUEFTS	6000.00^{e}	1730.00^{c}	100.33^{c}	35.53	110.33^{c}	4270.00^{d}	0.29
	300 NPKSB +100 Urea	10333.30^{abc}	2760.00^{a}	118.33^{ab}	39.00	120.33^{ab}	7573.30^{ab}	0.27
	300 NPKSZn +100 Urea	11666.70^{a}	2563.30^{ab}	121.86^{ab}	37.40	121.33^{a}	9103.30^{a}	0.22
	Mean	9333.33	2273.33	115.08	38.42	118.29	7060.00	0.25
	CV (%)	10.71	11.74	8.38	6.41	1.84	14.55	15.22
	SEM	192.45	51.36	1.40	0.47	0.42	135.87	0.01
	R^2	0.83	0.68	0.64	0.67	0.78	77.71	0.55
	Sig ($P < 0.05$)	**	*	*	ns	**	**	ns

Notes: **1) BM**: Biomass yield (kgha^{-1}), **GY**: Grain yield (kgha^{-1}), **PH**: Plant height (cm), **PL**: Panicle length (cm), **DM**: days to 50 % maturity, **StY**: Straw yield (kgha^{-1}), **HI**: harvest index, **CV**: Coefficient of variation, **SEM**: Standard error of the mean, **R^2**: Coefficient of determination,

2)**significant at $P>0.01$ but <0.05; *Significant at $P<0.01$; ns stands for not significant; Means within a column followed by the same letter are not significantly different from each other.

Table 4. Mean for yield and yield components of *tef,* combined over the years.

BF rate (kgha^{-1})	**BM**	**GY**	**PH**	**PL**	**DM**	**StY**	**HI**
50 NPSZnB +100 Urea	8333.33^{bc}	2020.00^{bc}	106.23^{bc}	35.31^{b}	116.67	6313.00^{bc}	0.26
100 NPSZnB +100 Urea	8833.00^{bc}	2076.70^{bc}	107.40^{bc}	36.33^{ab}	115.00	6757.00^{bc}	0.25
150 NPSZnB +100 Urea	10333.00^{ab}	2290.00^{ab}	113.50^{ab}	38.75^{a}	115.33	8043.00^{ab}	0.23
200 NPSZnB +100 Urea	10000.00^{ab}	2215.00^{abc}	114.83^{ab}	38.70^{a}	116.67	7785.00^{ab}	0.23
300 NPSZnB +100 Urea	11667.00^{a}	2450.00^{a}	121.63^{a}	38.45^{a}	116.67	9217.00^{a}	0.21
100 NPS +100 Urea	10667.00^{ab}	2166.70a^{bc}	110.16^{b}	37.43a^{b}	117.17	8500.00^{ab}	0.21
QUEFTS	7000.00^{c}	1906.70^{c}	99.83^{c}	35.10^{b}	111.83	5093.00^{c}	0.28
Mean	9547.61	2160.71	110.51	37.15	115.61	7386.90	0.24
CV (%)	19.47	11.31	6.55	6.09	3.20	24.39	19.58
SEM	286.87	37.72	1.12	0.35	0.57	278.03	0.01
R^{2}	0.69	0.59	0.85	0.89	0.59	0.67	0.61
Sig ($P < 0.05$)	**	*	*	*	ns	**	ns
Year* BF rate	ns	ns	ns	ns	ns	ns	ns

Notes: **1) BM**: Biomass yield (kgha^{-1}), **GY**: Grain yield (kgha^{-1}), **PH**: Plant height (cm), **PL**: Panicle length (cm), **DM**: days to 50 % maturity, **StY**: Straw yield (kgha^{-1}), **HI**: harvest index, **CV**: Coefficient of variation, **SEM**: Standard error of the mean, **R^{2}**: Coefficient of determination, **Sig**: Statistical significance ($P<0.05$), whereby (*) symbolizes significance at $P>0.01$ but less than 0.05.

2) Means within a column followed by the same letter are not significantly different from each other.

Considering only higher rates of blends, our finding was consistent with that of Eyasu *et al.,* (2019), who reported that blend fertilizers containing Zn and B had almost no difference over NPS and DAP from an agronomic viewpoint on the yield of bread wheat in different soils and sites of the country. The difference between most blend rates with each other was also non-significant. This is in agreement with the account of Teshome *et al.,* (2019) for the statistically similar effect of many rates of NPSZnB on yield of tef on Vertisols of the central highlands of the country. It also corresponded to EIAR (2017) report which compared the responses of wheat, maize, and barley to DAP and urea top-dressing with seven NPS-based fertilizers. In almost all crops, there was no statistically significant difference in grain yield. In conformity to the conclusion by Amare and Abebe (2015) and Anteneh and Angaw (2015), this study accepted N, P and K as the most limiting nutrients. In contrast, other studies (Bereket *et al*., 2011; Hillette *et al*., 2015; Alemu *et al.,* 2016) reported the importance of using secondary nutrients and micronutrients with N and P.

Biomass and plant height for the highest nutrient containing treatment was higher and statistically dissimilar with most treatments. Apart from the effect of secondary nutrients and micronutrients, this might be possibly linked with the higher quantity of macronutrients. For instance, Fissehaye *et al*., (2009) and Haftamu *et al*., (2009) reported higher plant height of tef for high amount of N fertilizer. That is attributable to N favoring plant growth, internode elongation, photosynthesis and metabolism and assimilated production (Metwally *et al*., 2011) which result in higher stature of *tef* plants, the effect of year on the efficiency BF rates (Year*BF rate) was insignificant for all parameters considered.

3.2 Soil Physicochemical Properties and *Tef* Yield Correlation

Pearson's r correlation between *tef* grain and straw yield with soil properties revealed that there was a positive and statistically significant correlation between grain and straw yield with available P and Mn. In contrast, there was a negative and significant correlation between grain and straw yield with K and organic matter (OM). Moreover, micronutrients Zn and B are positively correlated with grain and straw yield. The addition of K revealed insignificant positive correlation with yield. In addition, TN (total nitrogen) was to some extent negatively correlated with yield (Table 5).

Table 5. Correlation between soil physicochemical properties and *tef* yield, 2018

	GY	**StY**	**pH**	**Ca**	**Mg**	**K**	**Na**	**CEC**	**AP**	**S**	**B**	**Fe**	**Mn**	**Cu**	**Zn**	**OC**	**OM**	**TN**	**C:N**
GY	1.00																		
StY	0.87**	1.00																	
pH	0.15	0.24	1.00																
Ca	-0.31	-0.02	0.18	1.00															
Mg	0.43	-0.00	-027	-0.74*	1.00														
K	-0.67*	-0.72*	0.14	-0.01	0.04	1.00													
Na	0.35	-0.05	0.08	-0.35	0.75*	0.09	1.00												
CEC	0.19	0.14	-0.09	0.57	0.04	-0.13	0.24	1.00											
AP	0.85*	0.78*	0.35	-0.24	0.38	-0.28	0.22	0.20	1.00										
S	0.49	0.55	0.41	-0.23	-0.23	-0.01	-0.01	-0.14	0.74*	1.00									
B	0.57	0.18	0.12	-0.56	0.85**	-0.07	0.92**	0.11	0.45	0.24	1.00								
Fe	0.66	0.30	0.16	-0.51	0.63	-0.19	0.52	0.09	0.63	0.17	0.63	1.00							
Mn	0.77*	0.62	0.21	-0.50	0.30	-0.58	0.34	-0.28	0.54	0.22	0.52	0.67*	1.00						
Cu	0.13	0.14	-0.05	-0.08	-0.21	-0.44	-0.47	-0.05	0.03	-0.22	-0.34	0.32	0.23	1.00					
Zn	0.38	0.62	0.01	-0.02	-0.18	-0.33	-0.58	0.05	0.55	0.49	-0.33	0.02	0.06	0.40	1.00				
OC	0.39	0.30	0.44	-0.07	0.11	0.02	0.02	-0.02	0.60	0.47	0.10	0.65	0.37	0.28	0.17	1.00			
OM	-0.67*	-0.72*	0.14	0.01	0.04	1.00**	0.09	-0.13	-0.28	-0.00	0.07	-0.19	-0.58	-0.44	-0.33	0.02	1.00		
TN	-0.00	-0.23	0.37	-0.42	0.45	0.54	0.64	-0.35	0.13	0.23	0.57	0.31	0.25	-0.61	-0.54	0.26	0.12	1.00	
C:N	0.19	0.37	-0.04	0.38	-0.43	-0.47	-0.66	0.21	0.19	0.09	-0.55	0.06	-0.01	0.74	0.58	0.44	-0.47	-0.73*	1.00

** Correlation significant at P<0.01; *significant at P<0.05.

3.3 Economic Analysis Using Partial Budget

The partial budget analysis carried out for the 2018 yield data revealed the highest net benefit for the highest rate of the NPSZnB blend, 300 NPSZnB+100 kgha^{-1} urea and for both of the K containing blends, 300 NPKSB +100 kgha^{-1} Urea and 300 NPKSZn +100 kgha^{-1} urea. The former blanket recommendation (different sources), i.e., 100 NPS+100 urea kgha^{-1}, was a profitable fertilizer rate with higher MRR (%) than the QUEFTS rate (Smaling and Janssen 1993) and 50 NPSZnB + 100 urea kgha^{-1} and it dominated 100 NPSZnB+100 urea kgha^{-1} and 150 NPSZnB+100 urea kgha^{-1}.

Table 6. Partial budget analysis, according to CIMMIYT (1988)

BF rate (Kgha^{-1})	**Crop yield** (Kgha^{-1})				**Gross Field Benefits (GFB)** (ETBha^{-1})			**Variable cost and Net Benefit** (ETBha^{-1})		**D**	**MRR** (%)
	Avg.GY	Avg.StY	Adj.GY	Adj.StY	Grain	Straw	Sum	TVC	NB		
QUEFTS rate	1730.00	4270.00	1557.00	3843.00	38925.00	15372.00	54297.00	1035.30	53261.70		
50 NPSZnB +100 Urea	2090.00	5576.70	1881.00	5019.03	47025.00	20076.12	67101.12	2003.00	65098.12		1223.15
100 NPS+100 Urea	2200.00	7133.30	1980.00	6419.97	49500.00	25679.88	75179.88	2524.00	72655.88		1450.63
100 NPSZnB+100 Urea	2186.70	6813.30	1968.03	6131.97	49200.75	24527.88	73728.63	2737.00	70991.63	D	
150 NPSZnB+100 Urea	2263.30	6736.70	2036.97	6063.03	50924.25	24252.12	75176.37	3471.00	71705.37	D	
200 NPSZnB+100 Urea	2176.70	7823.30	1959.03	7040.97	48975.75	28163.88	77139.63	4205.00	72934.63		16.58
300 NPSZnB+100 Urea	2490.00	8510.00	2241.00	7659.00	56025.00	30636.00	86661.00	5673.00	80988.00		548.59
300 NPKSB +100 Urea	2760.00	7573.30	2484.00	6815.97	62100.00	27263.88	89363.88	5893.27	83470.61		1127.08
300 NPKSZn +100 Urea	2563.30	9103.30	2306.97	8192.97	57674.25	32771.88	90446.13	6134.00	84312.13		349.57

Notes: Avg.GY= average grain yield of each treatment.

Avg.StY= average biomass yield of each treatment.

Adj.GY= average grain yield adjusted downwards by 10%.

Adj.StY= average straw yield adjusted downwards by 10%.

Gross field benefits (sum) = (Adjusted grain yield (kg/ha) * field price of the crop (ETB/kg) + (Adjusted biomass yield (kg/ha) * field price of the straw (ETB/kg).

TVC = Total variable cost.

NB= Net benefit for each treatment calculated as Gross field benefits (ETB/ha) - total costs that vary (ETB/ha).

D= Dominance, any treatment that has net benefits that are less than or equal to those of treatment with lower costs that vary considered dominated and left out of calculating the marginal rate of return (MRR).

MRR (%) = Marginal rate of return (i.e. the marginal net benefit between two non-dominated treatments arranged in ascending order of total variable cost (TVC); calculated by dividing the change in net benefit by the change in costs * 100.

The fertilizer rate, 200 NPSZnB+100 urea kgha^{-1} was below the minimum acceptable rate of return (MARR), which, in this case, was set at 100% MRR between two non-dominated fertilizer treatments. Therefore, considering MARR from NPSZnB blend rates, 300kgha^{-1} was economically feasible and both of the K containing blends were somewhat better than the profitable NPSZnB rate (Table 6). Nevertheless, the profit might have to do with the relatively high amount of N and P in the high blend rates than the addition of micronutrients B and Zn; with that high rate, NPS and DAP might have produced comparable economic margins. For instance, Negash and Israel (2017), evaluating blend fertilizers, concluded that ‘the profit potential’ was generally much greater with the application of N and P compared with K and micronutrients. To maximize profit, they stressed that farmers should get adequate access to single nutrient and di-nutrient compound fertilizers.

4. Conclusion

From this study, we conclude that the application of blended fertilizers containing B and Zn on Vertisols of central highlands did not have significant yield benefits over the former DAP and NPS based recommendations on tef; only at a very high rate (300kgha^{-1}) did NPSZnB significantly increase yield. The design of the experiment in which the maximum NPSZnB rate was applied had significant effect on crop yield, but the design did not enable us to differentiate whether the effect on yield was attributable solely to the higher N and P contents or to micronutrients or to both the higher N and P contents or to micronutrients. However, regardless of their nutrient composition, no significant yield difference was revealed by the application of equivalent rates of the blends with NPS (100 kgha^{-1}) and DAP (150 kgha^{-1}). This draws attention on the worth of adding Zn and B at the expense of N and P. The addition of K at higher rates than B and Zn reduced N and P from NPS. But the K containing blend gave higher yield than the B and Zn containing blend at equivalent rate. Therefore, irrespective of the amount, adding K seemed to improve yield.

Former formulations of DAP and NPS would also produce equivalent economic margins when applied at a higher rate than 100 NPS and 150

DAP. The higher rate of both NPSZnB and K containing blends have a higher MRR than the set MARR of 100% between non-dominated treatments. But the environmental sustainability of the higher rates of blended fertilizers should be known before recommending for an improved financial return.

Generally, additional studies should be carried out in order to arrive at conclusive results about the results of the application of micronutrient containing fertilizer blends at different rates. By conducting experiments with the same amount of N and P and different rates of each secondary nutrient and micronutrient, it may be possible to distinguish the yield attributes of every element. In addition, evaluating the financial return of the same blends but at higher rates, NPS and DAP would also make the financial return information conceivable.

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