Soil-test Crop Response Based Phosphorus Calibration Study under Balanced Fertilization of Maize (*Zea mays* L.) on Nitisols in North West of Ethiopia

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Abstract

Phosphorus is the second yield limiting nutrient next to nitrogen in the major maize growing area of west Amhara, Ethiopia. Hence, efficient management of P nutrient is critically required. A field experiment was conducted for six years (2014-2019) on permanent fields to develop phosphorus requirement equation to recommend P fertilizer based on soil test results for improving maize (Zea mays L.) productivity. The experiment was started by creating different artificial phosphorus gradient fields in the first 2 years (2014-2015). For the two consecutive cropping years (2018-2019), plot based field experiment was conducted on different P level gradient fields. The field experiment had seven treatments with the levels of (0, 10, 20, 30, 40, 50 and 60) P kg ha^{-1}. Randomized complete block design (RCBD) with 3 replications were used. All treatments received equal levels of N, K and S fertilizers in all gradient fields through the cropping years. Urea, Triple Supper Phosphate (TSP), Muriate of Potash (KCl) and Calcium sulfate (CaSO4) were used for N, P, K and S fertilizer sources, respectively. Improved maize variety (BH-540) was used for this experiment. In all cropping years, P, K and S fertilizers were applied in band at planting while, N was applied in three equal splits (1/3 at planting, 1/3 at 40-45 days after planting and 1/3 at knee height). All other crop management practices were implemented as per the recommendations. Soil samples were taken in P gradient formation period, as well as in all cropping years from each experimental plot at 0-20 cm depth and selected chemical soil parameters (pH, SOC, and available P) were analyzed at Adet Agricultural Research Center (AARC) soil laboratory. The yield and yield components such as plant height, grain and biomass yield of maize showed a highly significant each and combined years. Soil phosphorus values also showed increasing trend as the applied phosphorus amount increased within the defined treatments. Finally, 8 mg kg^{-1} soil P was determined as phosphorus critical point (Pc) and 17.3 phosphorus requirement factor (Pf) values were obtained from over-year combined analysis result using the Cate-Nelson graphical method. Using these two critical values, it is better to do a verification study on the farmer fields with similar agro ecology and soil types to validate whether the developed equation is economically acceptable or not.

Keywords: Cate-Nelson, equation, maize, phosphorus, requirement,

Introduction

Maize is one of the three most important cereals following wheat and rice for food security at the global level and very important in the diets of the poor in Africa and Latin America (Bekele et al., 2011 and FAOSTAT, 2010). In many developed countries and the emerging economies of Asia and Latin America, maize is increasingly being used as an essential ingredient in the formulation of livestock feed (Bekele et al., 2011). In Ethiopia, maize is the most widely cultivated cereal crop with 16% area coverage, 26% production potential and 6.5 million tons of production (CSA, 2014). Estimated average yields of maize for smallholder farmers in Ethiopia is about 4.2 tons ha^{-1} (Kiflemariam et al., 2022). To solve soil fertility problems and maximizing maize yield, different research activities have been undertaken in Ethiopia using various fertilizer sources (Birhan et al.,2017).

However, soil fertility depletion became critical challenge for maize production in Ethiopia. To reverse the situation and advices best fit recommendations for small holder farmers, monitoring and frequent reviewing of soil fertility status are important. In Ethiopia nitrogen (N) and phosphorus (P) are the most yield limiting soil nutrients (Tadele et al., 2018). It has been considered as a major factor for limiting crop productivity and recommended to apply in large amounts on the soil since the green revolution to sustain production of agricultural systems (Tilman et al.,2002). Relative to N, recovery of P fertilizers by plants is very low due to its high fixation capacity in the soil (Balemi and Negisho, 2012).

One of the best nutrient recommendations is to calibrate and validate the nutrient requirements using long term experimental data. Nutrient calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current nutrient recommendations (McKenizie and Kryzanowski, 1997). It enables to revise fertilizer recommendations based on soil and crop types, pH and soil moisture content at time of planting. Soil tests are designed to help farmers to know the available nutrient status of their soil. Once the nutrient status determined, it is possible to decide how much nutrients to be applied to get economically acceptable yields (Getachew and Berhane, 2013 and (Getachew et al.,2015).

However, for P calibration and validations, determination of soil P critical and soil P requirement factor values for major crops at major agro ecology and soil types for Western Amhara is lacking. Hence, to bridge this gap, Adet Agricultural Research Center (AARC) proposed a long-term soil test-based and site-specific P calibration study under balanced fertilization for maize on Nitisols.Therefore, the objective of this research were to develop P calibration equation and recommendations of P fertilizer requirement

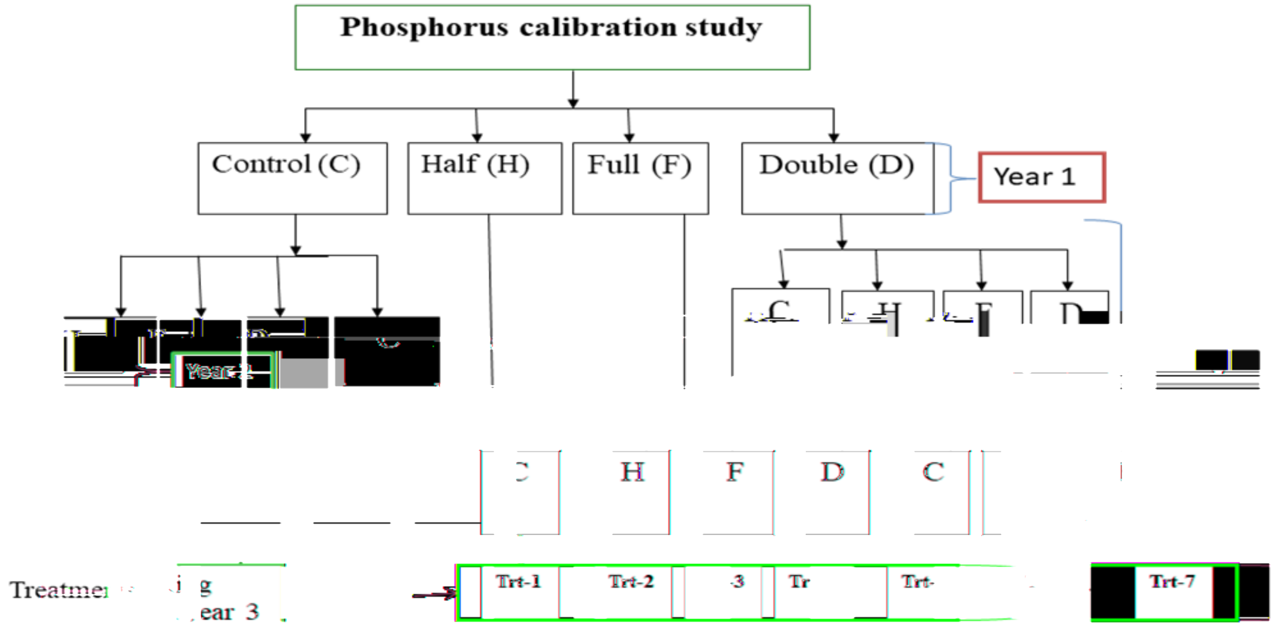

Figure 1. Schematic field layout for the above mentioned experiment

Soil Sampling and Analysis Procedure

One initial, 4 in 2014 (before second gradient formation) and 16 in 2015 (before plot level experiment started) composite soil samples were taken from each artificially created low, medium and high P containing field with the depths 0-15cm. All the collected composite soil samples were subjected for some chemical soil analysis (soil pH, SOC, available P). Following Landon (1991) available P value for initial soil was under low ratting level (3.3 P mg kg^{-1}) (Table 1). Similarly, artificially created fields were classified as low (<5 P mg kg^{-1}), medium (5-15 P mg kg^{-1}) and high (>15 P mg kg^{-1}) categories after 2015 cropping season. Therefore, from the total of 16 sub-sub plots, 3 were in low category, 9 were in medium and the remaining 4 were in high category and we considered as replications (Table 2).

Similar to gradient formation years, during experimentation period soil samples were collected continuously from each piece of plot at a depth 0-15cm before the next crop planting. All the sampled VRLOV ZHUH DLU GULHG DQG VLHYHG ” PP IRU DQDO\VLV oil pH-H_2O was determined in soil-water suspensions of 1:2.5 ratios according to Taye et al. (2002) while, AP was analyzed using (Olsen, 1954) and SOC was also determined following (Nelson and Sommer, 1982) method.

Table 1. Initial soil data values of the four P gradient fields (2014)

Soil parameters	Initial	P gradient fields (2014)			
		Zero (0 kg ha^{-1} P_2O_5)	Half (57.5 kg ha^{-1} P_2O_5)	Full (115 kg ha^{-1} P_2O_5)	Double (230 kg ha^{-1} P_2O_5)
pH- H_2O	5.70	5.6	5.63	5.73	5.68
Ava.P (Ppm)	3.30	3.56	4.79	3.1	5.44
SOC (%)	1.659	1.812	1.592	1.372	1.847

Table 2. Soil data values for each P gradient field in the second year (2015)

Soil parameters	P gradient fields (2015)															
	ZZ	ZH	ZF	ZD	HZ	HH	HF	HD	FZ	FH	FF	FD	DZ	DH	DF	DD
pH- H_2O	5.50	5.58	5.64	5.51	5.66	5.72	5.64	5.61	5.78	5.63	5.55	5.41	5.64	5.58	5.58	5.30
Ava.P (Ppm)	4.08	5.31	8.55	16.52	5.05	4.01	7.19	9.65	4.59	6.99	14.38	16.00	7.64	8.35	18.40	21.32
SOC (%)	1.384	1.165	1.321	1.137	1.319	1.514	1.537	1.311	1.402	1.376	1.277	1.341	1.404	1.260	1.704	1.521

Note: ZZ=zero,zero, ZH=zero,half, ZF=zero,full, ZD=zero,double, HZ=half,zero, HH= half,half, HF=half,full, HD=half,double, FZ=full,zero, FH=full,half, FF=full,full FD=half, double, DZ= double,zero, DH= double,half, DF= double,full, DD=double, double.

Determination of critical P concentration

Critical P value was determined following the Cate-Nelson graphical method where soil P values were put on the X-axis and the relative grain yield values on the Y-axis. The Cate-Nelson graphical method was divided the X-Y scatter diagram into four quadrants and maximizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants (Nelson LA and RL Anderson, 1997).

Steps for Cate-Nelson graphical methods for Pc determination:

1. Relative grain yield percentage values were obtained from all artificialy created fields using the formulas indicated below.

$$\text{Relative yield percentage (RYP)} = \frac{Yield\ from\ each\ unit}{Maximum\ Yield} * 100 \ldots\ldots Eq1$$

2. Soil test values for the nutrient being studied should be obtained from all the locations. The control plot test values should be averaged. Thus, there will be a single percentage yield and one soil test value for each location.
3. The scatter diagram of relative yield percentage (Y-axis) versus soil test value (X-axis) is plotted on arithmetic paper. The range in values on the Y-axis is 0 to 100%.

4. A piece of clear plastic having roughly one and one-half the dimensions of the graph is cut out for use as an overlay. A pair of intersecting perpendicular lines is drawn on the overlay with black ink in such a way that it is divided in to four quadrants.
5. The overlay is moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). The positions of the lines on the overlay with respect to the axes of the graph are transferred to the graph by making marks on the edges of the graph. The two intersecting lines are then drawn lightly on the graph with pencil. The point where the vertical line crosses the X- D [L V L V G H I L Q H G D V .µ F U L W L F D O V I

Determination of P requirement factor (Pf)

Phosphorus requirement factor is the amount of P in kg needed to raise the soil P by 1 mg kg^{-1} soil when the initial soil available P is below the Pc value. It was calculated using available P values in samples collected from unfertilized and fertilized plots. Therefore, Pf and the rate of f(e)4(r-P).0002Q

Results and discussion

Yield and yield components

Plant height and Ear length

The plant height of maize showed highly significant differenc H S ” D P R Q J W U H D means due to the applied phosphorus fertilizer rates through both the cropping years and the combination of the two cropping seasons. Including the combined mean result, minimum plant height means in each year was recorded at zero input of phosphorus fertilizers used. However, the maximum plant height values were observed at different levels of phosphorus fertilizer used. However, as compared to other treatments maximum plant height was observed when 50 P kg ha^{-1} phosphorus fertilizers was applied (Table 3).

In contrast to S O D Q W K H L J K W H D U O H Q J W K R I P D L] H G L G Q ¶ W V K R treatment means. In this parameter, we observed an irregular trend of ear length among the treatment means (Table 3).

Table 3. Response of the applied phosphorus fertilizer on maize plant height and ear length

Treatment	Plant height (cm)			Ear length (cm)		
	2018	2019	Year-combined	2018	2019	Year-combined
0	190.5	209.8	200.2	17.5	18.5	18.0
10	196.3	212.8	204.5	17.5	18.7	18.1
20	197.3	219.6	208.5	17.8	18.8	18.3
30	197.5	220.8	209.1	17.4	18.4	17.9
40	196.2	222.3	209.2	17.3	18.5	17.9
50	200.1	229.2	214.6	17.2	18.5	17.8
60	199.9	227.0	213.5	17.6	18.2	17.9
Mean	196.8	220.2	208.5	17.5	18.5	18.0
LSD(0.05)	4.8	5.3	4.9	0.5	0.5	0.4
Pr.	**	**	**	NS	NS	NS
CV(%)	6.1	6.0	8.3	7.2	7.0	7.6

Grain and Biomass yields

As shown in the results in Table 4, grain yield of maize showed a highly significant difference S” DPRQJ WKH WUHDWPHQW PHDQV ilizers in each cropping WKH DSSO season as well as the combined result over years. Except slightly irregularities, grain yield of maize showed linearly increasing trend as the rate of phosphorus fertilizer used increased in all cropping years as well as in over-year combined result. The minimum value of grain yields was recorded at the control treatment (zero P input). While, the maximum one recorded at treatments received 50 and 60 P kg ha^{-1} (Table 4). Similar to the grain yield values, the minimum maize biomass yield was recorded on the control treatment (zero P input) in each cropping years as well as in combined result. Furthermore, maximum biomass yields were also obtained at treatments received 50 and 60 P kg ha^{-1} in 2018 and 2019, respectively (Table 4).

Table 4. Response of the applied phosphorus fertilizer on maize grain and biomass yields

Treatment	Grain yield (kg)			Biomass yield (kg)		
	2018	2019	Year-combined	2018	2019	Year-combined
0	5992.3	5186.6	5589.4	14050.9	16800.9	15425.9
10	6663.4	6447.6	6555.5	16074.1	20511.6	18292.8
20	7302.4	7076.0	7189.2	17722.2	22412.0	20067.1
30	7551.7	7414.1	7482.9	18259.3	24201.4	21230.3
40	7489.5	7641.5	7565.5	17546.3	24171.3	20858.8
50	7574.3	7792.8	7683.6	18652.8	24745.4	21699.1
60	7747.0	7754.7	7750.9	18606.5	25270.8	21938.7
Mean	7188.7	7044.8	7116.7	17273.1	22587.6	19930.4
LSD(0.05)	442.8	384.7	295.3	1291.8	1168.2	1164.6
Pr.	**	**	**	**	**	**
CV(%)	15.3	13.6	14.6	18.6	12.9	20.6

Critical P concentration (Pc) and P requirement factor (Pf)

Available soil P values showed a linear increasing trend as the applied P fertilizer increased in all cropping years as well as in the combined years result. However, when we compare across years, 2019 available P values showed slightly a decreasing trend from 2018 result which might be happened due to climatic variations (Figure 2).

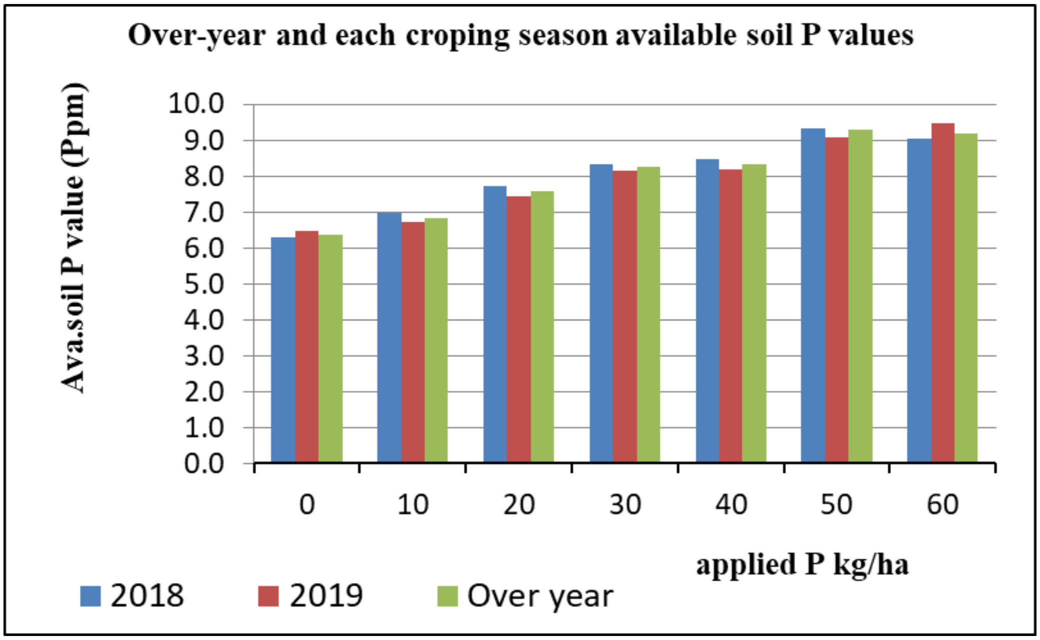

Figure 11. Applied P verses available soil P values for two trial seasons and combined over years

The critical P concentration (Pc) values were determined from the scatter diagram drawn using relative grain yields of maize and the corresponding soil test P values for all P levels (0 ±60 kg ha^{-1}). Based on the Cate-Nelson Pc determination method, Pc values in 2018, 2019 and over-year combined were 7, 8 and 8 P mg kg^{-1}, respectively (Figure 3) which is by far different from the findings reported by (Yihenew et al, 2003). All the mentioned Pc values could help to achieve a minimum of 70% of the maize grain yield production without any stress if other factors were found normal.

However, if the soil test values found below the critical levels, additional information is needed on the amount of P required for elevating the soil P to the required level. This is the P requirement factor (Pf) which is defined as the amount of P required to raise the soil P by 1 mg kg^{-1}soil and computed from the difference between available soil test P values from plots which received (0 ±60) kg P ha^{-1} using the formula indicated at (Eq 2). Therefore in the study, calculated Pf values in 2018, 2019 and their over-year combined results were 14.7, 16.3 and 17.3, respectively (Table 5).

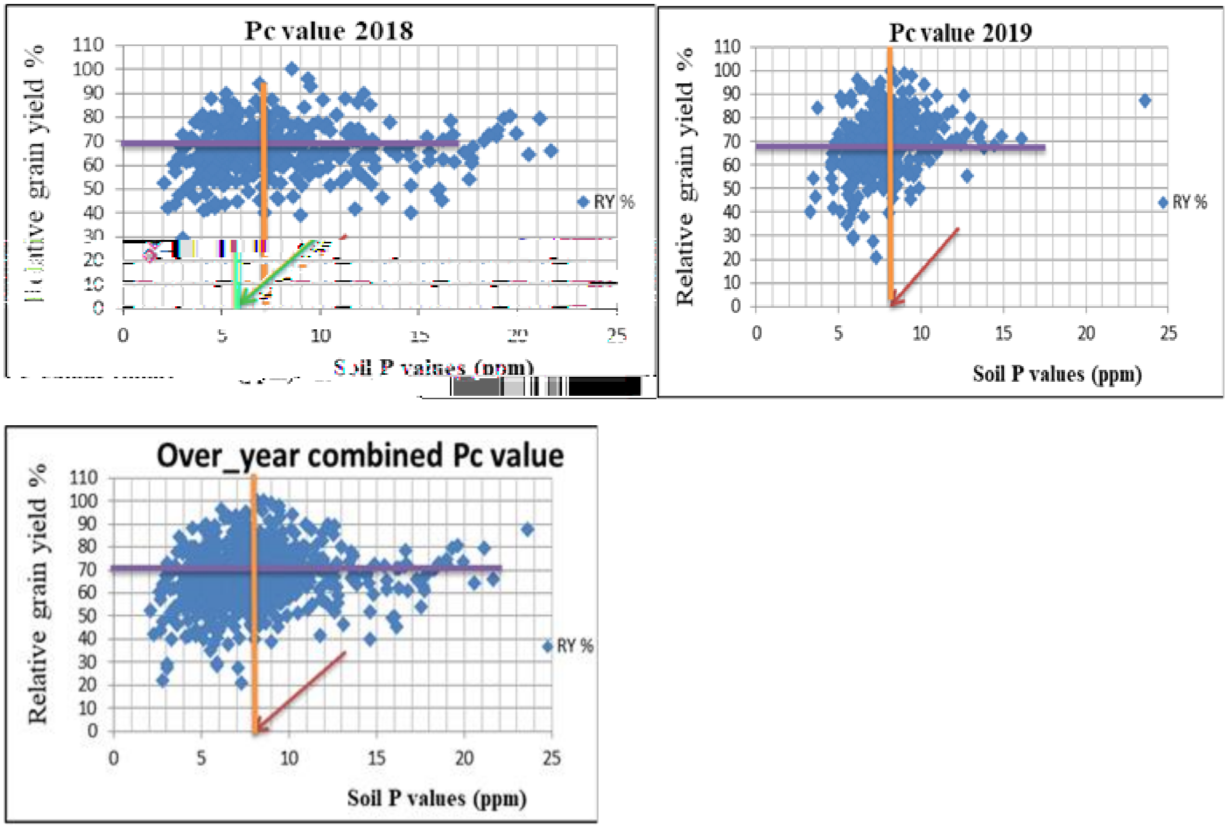

Figure 12. Cate-Nelson graphics for Pc values determination. The point on arrows indicates Pc for maize on Nitisols

Table 5. The two years and over-year combined phosphorus requirement factors (Pf) values on maize

P (kg /ha)	2018				2019				Over-year combined			
	Range	Mean	P increase over control	Pf	Range	Mean	P increase over control	Pf	Range	Mean	P increase over control	Pf
0	2.1-14.8	6.31			3.3-9.6	6.40			2.08-14.83	6.35		
10	2.7-14.4	6.98	0.9	11.0	4.6-9.9	6.71	0.6	15.6	2.65-14.43	6.84	0.6	17.2
20	3.0-18.3	7.72	1.7	12.1	4.8-10.9	7.44	1.4	14.6	3.03-18.29	7.58	1.3	15.2
30	3.0-17.8	8.33	2.3	13.3	4.6-12.8	8.15	2.1	14.4	2.97-17.75	8.24	2.0	15.2
40	3.5-19.3	8.48	2.4	16.6	5.1-13.5	8.18	2.1	19.0	3.47-29.30	8.33	2.1	19.3
50	4.0-20.6	9.33	3.3	15.3	5.1-23.6	9.28	3.2	15.6	4.01.8-23.60	9.31	3.0	16.4
60	3.2-21.7	9.05	3.0	20.1	5.7-16.1	9.34	3.3	18.3	3.14-21.66	9.20	2.9	20.4
				14.7				16.3				17.3

Pf =is phosphorus requirement factor

Conclusion and recommendations

The study provided acceptable Pc and Pf values which could help users as a baseline for soil-test crop response based phosphorus fertilizer recommendation for increasing maize productivity on Nitisols in North West Ethiopia after a validation study done. In this study, the yield and yield components such as plant height, grain and biomass yield of maize showed a highly significant GLIIHUHQFH S” DPRQJ WUHDWPHQW PHDQV GXH WR G
both individual and over years combined analysis.

Soil phosphorus values also showed an overall increasing trend due to the accumulation of applied phosphorus amounts over years. Finally, 11.5 P mg kg^{-1} Pc and 23.8 Pf values were obtained from over-year combined analysis result. Using these two important values, it is better to do a verification study on the farmer fields having similar agro ecology and soil types with the study site to determine either the developed equation is economically acceptable or not in farm get price level on maize production.

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