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Productive potential of watermelon under different plant spacings in the semi-arid region of Brazil

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Abstract

This study aimed to evaluate the growth and development of watermelon plants under different plant spacings in the Semi-arid region of Brazil. A randomized block experimental design was used with four treatments and eight replications. Data were submitted to analysis of variance and the Tukey test. The treatments were composed by the following spacings: T1: 3.0 x 0.8 m; T2: 3.0 x 0.6 m; T3: 2.0 x 0.8 m and T4: 2.0 x 0.6 m (spacings between rows and between plants, respectively). The plant length, number of leaves, stem diameter, leaf area, number of flowers, number of fruits per plant, average fruit weight, total fruit production, number of commercial fruits, average weight of commercial fruits, total weight of commercial fruits and percentage of commercial fruits were evaluated in this study. There was a significant difference in the growth traits: stem diameter and leaf area at 30 days after sowing (DAS), and plant length, stem diameter and number of leaves at 60 DAS, with no significant statistical difference in the remaining days and nor for the number of flowers. The watermelon plants showed adequate vegetative and productive development at the 2.0 x 0.8 m plant spacing in the edaphoclimatic conditions of the semi-arid region under study. This spacing is well suited to small producers in the semi-arid region, which are dependent on agriculture with small areas and can obtain good productivity with no need to use larger areas due to spacing.

Keywords: *Citrullus lanatus,* Growth, Productivity.

Introduction

Watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai] is a Cucurbitaceae plant. It is cultivated all over the world with a significant social and economic importance, especially in the Northeast of Brazil, where this fruit, among other vegetables, is produced by family farmers and/or small farmers, since it requires lower production cost and is easily handled compared to other vegetables (EMBRAPA, 2010).

The world watermelon production in 2016 was 117.022 million tons, grown on 3.5 million hectares, with an average yield of 30.1 t ha^{-1} (FAO, 2017). In Brazil, 1,321,394 tons of watermelon were produced in 2017 in a harvested area of 99,290 ha. The Northeast region is the main producer of this vegetable, and its production exceeds 60% of the national watermelon production. In the northeast region, the main producers states are: the states of Bahia (163,361 t) and Rio Grande do Norte (124,205 t) (IBGE, 2017). The accounted exceeded 1.3 million tons produces, counts with the Northeast and the South regions producing 33.54% and 26.85%, respectively, of the total national production (Silva et al., 2015).

In watermelon cultivation in Brazil, the spacing used in drip-irrigated areas ranges from 2.50 to 3.00 between rows and 0.50 to 1.00 m between plants, with only one plant per pit (Nascimento & Silva, 2014). According to Walters (2009), the plant spacing may also range from 2.0 to 3.0 m between rows and 0.7 to 2.0 m between plants in the row with one or two plants per pit.

In the Northeast, in the São Francisco River Valley, the highest yield of 42.46 t ha-1 was obtained with the 3 m row spacing and the spacing between plants of 0.6 and 0.8 m resulted in higher yields with 42.50 and 45.29 t ha-1, respectively, however, there were no significant differences between them (Ramos et al., 2012).

Campos et al. (2019) studying the density of plants and thinning in the production of watermelon hybrids, at different times found that the density of the plants had an isolated effect, with a linear increase in productivity, as the density increased, with the maximum density (6,000 plants/ha - 2.5m spacing between rows x 0.65 m between plants), productivity was 92.9% higher than medium-density (3,000 plants/ha - 2.5m between rows x 1.33m between plants).

Watermelon productivity can be increased by the increase in plant density, up to a certain point, and it can decrease due to the competition between plants (Adlan and Abu-Sarra, 2018) with an ideal plant spacing of 70 cm. Higher planting density can maximize land use without impairing crop productivity (Celílio Filho et al., 2015).

The Semi-arid region is characterized by high temperatures, low air humidity, and low annual precipitation, in these drought-prone areas, the Northeast of Brazil is significantly affected by the deficit in rainfall and increased aridity (Gondim et al. 2017). These droughts occur naturally due to a change in the hydrometeorological regime, which affect producers in this region, causing risks to food security (Eakin et al. 2014). Thus, the use of irrigation in agriculture is a viable and essential way to establish crops and obtain food. The Caatinga is predominated in the semi-arid vegetation, the soil is considerably diverse, but they are mostly characterized as sandy Latosol (Gomes et al., 2018).

The average annual rainfall of the Brazilian semi-arid region is variable, it ranges from 1800 mm on the east coast to 400 mm in the center of the semiarid; the average air temperature ranges between 16.8 to 33.8 ºC and the evaporation exceeds 10 mm d^{-1} (Silva et al., 2006).

Considering the great importance of this crop and the lack of reliable information on the ideal spacing for the cultivation of watermelon in the semi-arid region of the Northeast region of Brazil, especially in the state of Piauí, this study aimed to evaluate the effect of different plant spacings in the productivity of the watermelon cultivar 'Crimson Sweet'.

Results and discussion

Table 2 lists the results of the growth at different spacings. A significant difference between the treatments was observed for stem diameter (SD) at 42, 49 and 56 days after sowing (DAS); for the leaf area (LA) at 42 and 49; for the number of leaves (NL) at 35 and 56, and the number of flowers (NFLO) at 56 and 63 and a non-significant difference in the remaining evaluations. Only the treatments (spacing) promoted significant effect on some phenological stages of watermelon plants, with a direct effect on SD and LA at 30 DAS and PL, SD, and NL at 60 DAS (Table 3). The significant effect on the traits observed in table 2 (SD at 30 and 60 DAS; LA at 30 DAS; PL, SD, and NL at 60 DAS) at their different developmental stages was due to the different plant spacing used, in which stands as the best option the treatment 3, with the spacing of 2 x 0.8 m. This behavior may also be linked to the American cultivar. The EMBRAPA (2010) recommends that American cultivars must be planted in greater plant spacing than Japanese cultivars. For irrigated cultivation, the plant spacing that resulted in the highest yield was 3 m x 0.8 m, but other spacings are also indicated, such as 2.0 x 0.5 m; 2.5 x 1.0 m or 3 x 1.0 m (Bellad and Umesh, 2018; Cecílio Filho et al*.,* 2015; Sylvestre et al., 2014). However, for detailed validation, further research is needed to evaluate watermelon performance at different plant phenological stages under different plant spacing.

In the first evaluation, at 30 DAS, a significant difference for SD and LA was observed in the treatment 3, thus standing as the best option for planting, probably because watermelon plants at this phenological stage takes advantage of its nutrient reserves. At 30 and 60 DAS, a constant growth was observed, as observed by Moreira et al. (2015). On both dates, the best treatment was T3 (2 x 0.8m) (Table 3) followed by treatment 1 (3 x 0.8m). The increase in stem diameter probably enables greater transport of reserves, providing better fruit development, besides the greater resistance to pest attack, since their cellular structures may be more organized (Taiz and Zeiger, 2013).

For the leaf area, as observed in Table 3, only at 30 DAS, there was a significant difference under the different spacings; the higher values were observed under the treatment 3 (2.0 x 0.8 m) ($p < 0.05$). Melo et al. (2014) mentioned that the constant growth of the leaf area indicates that the leaves (both in width and length) expanded their leaf area individually, to guarantee the production of photoassimilates for the fruits and the plant.

For plant length (PL), a significant difference was observed at 60 DAS, between T3 and T2, with T3 standing as the best treatment, and not differing from the other spacings. Moraes et al. (2007), evaluated the same growth analysis in a watermelon cultivar, at 30, 60, and 90 days, and also did not observe a statistical difference.

There was a significant difference ($P < 0.05$) in NFOL only at 60 DAS, where treatment 3 (2 m x 0.8 m) promoted the highest mean values for NFOL. This may have been due to the photoperiod that favors plant growth, and consequently, the increase in the number of leaves, and long hot days and warm nights (hot and dry summer), conditions considered ideal (Costa *et al.*, 2006). As part of the physiological process of plants, new leaves appear at each period, and also there is senescence and death of the older leaves. Possibly, this was one of the reasons for the difference in this variable in the different times of evaluations (Taiz and Zeiger, 2013).

Another explanation may be the fact that this research was carried out in the dry season, where, according to EMBARA (2010), the temperature becomes milder, and the plant spacing must be reduced, considering that the crop cycle increases from 15 to 30 days at this period. The authors recommend a plant spacing of 2.5 x 0.7 m or 2.5 x 1 m under these conditions, similar to that used in the treatment 3.

For planting density, the pressure exerted by the plant population strongly affects their development. For farmers, vegetative development is important because it influences the strategy that can be adopted on planting density and affects fruit size and productivity (Ramos et al., 2012).

Plant length, leaf area, stem diameter, number of leaves are linked together because it is a growth assessment (plant vegetative development). Another important point is that plant length, leaf area and stem diameter are influenced by carbohydrates produced by photosynthesis and hormone translocated from apical regions, which affects the fruit formation and production (Taiz and Zeiger, 2013).

Stem diameter depends more precisely on photosynthesis. The stem diameter developed better to the point of significant difference probably because it is influenced by plant spacing and photosynthetic factors, also improving the transport by xylem and phloem to the whole plant (Taiz and Zeiger, 2013). As observed in table 3, it is also verified that all traits evaluated herein correlate to T3: 2.0 x 0.8 m. This is justified because correlation "is a measure of bivariate association (strength) of the degree of relationship between two variables" (Hair et al., 2009). Moore (2007) conceptualizes correlation as the measurement of direction and the degree of linear relationship between two quantitative variables and for this reason, it was decided to correlate them by Pearson correlation, according to Table 4.

The table above shows the strong degree of correlation between variables studied, which suggests interconnection and direct selection of traits, which makes the research more laborious and justifies the evaluations of treatments.

Plant length was positively correlated with the number of leaves ($r = 0.996$), stem diameter ($r = 0.992$) and leaf area (r

Table 1. Soil chemical properties of Joaquim Isac Farm, located at Granada II, Francisco Santos city, State of Piauí, 2016.

Depth	pH	P	K	Na	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al	V
(cm)	- H_2O-	-----mg dm^{-3}-----			------------ cmol (c) dm^{-3}-----------				- %-
0-20	5.2	2.6	5.5	11.8	0.9	0.4	0.2	1.8	48.25
	Sand	Clay	Silt	MO	CC	PMP	Dp	Ds	
	----------------g kg^{-1}-----------------				-----kg kg^{-1}-----		-----Mg m^{-3}-----		
	620	280	100	16	0.25	0.16	2.65	1.38	

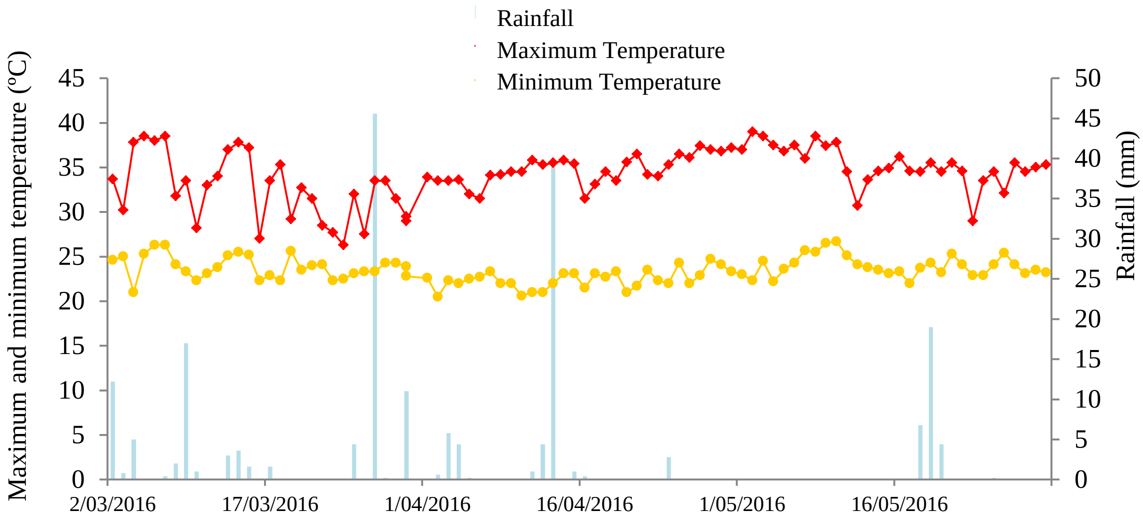

Fig 1. Daily variation of the maximum and minimum air temperature and rainfall during the experiment.

Table 2. Summary of the analysis of variance for the plant length (PL), stem diameter (SD), leaf area (LA), number of leaves (NL) and number of flowers (NFLO) at 30 and 60 days after sowing (DAS) according to the spacing used in the watermelon cultivation in Francisco Santos, State of Piauí.

SV	DF	QM (30 DAS)				
		AP (cm)	DC (cm)	AF (cm^2)	NFOL (u)	NFLO (u)
Treatments	3	0.825^{NS}	0.0051^{*}	8.321^{*}	0.068^{NS}	-
Blocks	7	0.518^{NS}	0.0025^{NS}	3.252^{NS}	0.218^{NS}	-
Errors	21	0.623	0.0025	2.265	0.098	-
Total	31					-
CV(%)		15.52	10.25	21.25	10.32	-
60 DAS						
Treatments	3	5.6246^{*}	0.0208^{**}	6.242^{NS}	0.524^{*}	0.007^{NS}
Blocks	7	1.241^{NS}	0.0063^{NS}	4.285^{NS}	0.454^{NS}	0.125^{NS}
Errors	21	1.320	0.0052	3.264	0.326	0.052
Total	31					
CV(%)		10.25	12.65	15.42	13.36	25.62

^{ns}Non-significant, * Significant at 5% probability and ** Significant at 1% probability by Fisher-Snedecor test.

Table 3. Mean values of plant length (PL), stem diameter (SD), leaf area (LA) and number of leaves (NL) according to the spacing used in the watermelon cultivation in Francisco Santos, State of Piauí.

Treatments	PL (cm)	LA (cm^2)	PL (cm)	SD (cm)	NL (u)
	-------30 DAS-----		--------------60 DAS------------		
T1: 3 x 0.8 m	0.285 ab*	5.422 ab	6.083 ab	0.424 ab	7.352 ab
T2: 3 x 0.6 m	0.274 b	4.246 b	4.589 b	0.394 ab	6.056 ab
T3: 2 x 0.8 m	0.325 a	6.625 a	6.303 a	0.518 a	8.465 a
T4: 2 x 0.6 m	0.275 b	5.245 ab	5.489 ab	0.385 b	5.882 b
C.V. (%)	10.25	21.25	10.25	12.65	13.36

C.V.%: coefficient of variation; *mean values followed by different letters in the same column are significantly different by Tukey's test at the 5% probability.

Table 4. Pearson correlation coefficients for plant length (PL), number of leaves (NL), stem diameter (SD) and leaf area (LA) according to the spacing used in the watermelon cultivation in Francisco Santos city, State of Piauí.

	PL	NL	SD	LA
PL	1			
NL	0.996	1		
SD	0.992	0.989	1	
LA	0.972	0.972	1.000	1

Table 5. Mean values for the number of fruits per plant (NFPP), average fruit weight (AFW) and total fruit production (TFP) according to the spacing used in the watermelon cultivation in Francisco Santos, State of Piauí..

Treatments	NFPP* (u)	AFW (kg)	TFP (t ha^{-1})
T1: 3 x 0.8 m	2.25 ab	6.75 a	46.25 b
T2: 3 x 0.6 m	1.25 b	5.90 b	40.65 c
T3: 2 x 0.8 m	2.50 a	7.15 a	52.12 a
T4: 2 x 0.6 m	1.25 b	5.25 b	39.90 c
C.V. (%)	26.41	4.96	4.03

C.V.%: coefficient of experimental variation; *mean values followed by different letters in the same column are significantly different by Tukey's test at the 5% probability level.

Table 6. Mean values of number of commercial fruits (NCF), average weight of commercial fruits (AWCF), total production of commercial fruits (TPCF), and percentage of commercial fruits (PCF) according to the spacing used in the watermelon cultivation in Francisco Santos, State of Piauí.

Treatments	NFC* (fruit ha^{-1})	AWCF (kg)	TPCF (t ha^{-1})	PFC (%)
T1: 3 x 0.8 m	4,280 a	7.97 a	33.80 b	73.17 ab
T2: 3 x 0.6 m	3,800 b	6.37 b	27.25 c	67.00 ab
T3: 2 x 0.8 m	4,370 a	8.50 a	39.55 a	76.02 a
T4: 2 x 0.6 m	3,750 b	6.17 b	24.95 c	62.54 b
C.V. (%)	3.97	5.0	6.24	7.57

*mean values followed by different letters in the same column are significantly different by Tukey's test at the 5% probability level.

= 0.972) with R^2 = 0.992, R^2 = 0.984 and R^2 = 0.945, respectively. Therefore, it is suggested that the 99.2% variation observed in watermelon PL can be explained by the variation in NL, 98.4% in the variation in SD, 94.5%, and LA, 100%, respectively. This is because NL, SD, and LA are components that are directly related to plant length and consequently to yield (Meira *et al.,* 2009), which may affect fruit production.

In Table 2, the number of leaves (NL) and stem diameter were statistically significant variables at 5% probability. Thus, it is observed that NL, in Pearson coefficient, is positively correlated with SD (r = 0.989) and LA (r = 0.972) and, consequently, R2 = 0.978, R2 = 0.945, respectively. Therefore, 97.8% variation in SD and 94.5% variation in LA occur because SD and LA are highly linked and correlated with NL. According to Moreira *et al*. (2015), watermelon development is correlated with production and yield.

In the SD column, LA and SD are perfectly correlated presenting the highest R2 = 1.00, which reports the importance of PL, NL, SD and LA to choose the most appropriate treatment, which in this research was T3 (2.0 x 0.8 m) and that all studied traits are correlated with fruit ripening and yield (Meira et al., 2009), reflecting the higher fruit production.

For the number of fruits per plant (NFPP), treatments 1 and 3 showed the highest values, with no significant difference (Table 5), however, treatment 1 did not differ from treatments 2 and 4. Resende and Costa (2003) used the 3.0 x 0.80 m spacing and achieved a mean number of fruits per plant of 1.35, lower to the obtained in our study.

For the fruit weight (AFW), treatments 1 and 3 also did not differ from each other, with higher values than the other treatments. Ramos et al. (2009) obtained a mean fruit weight of 6.33 kg per plant with the cultivar Crimsom Sweet, while in the study carried out by Oliveira et al. (2015), fruit mass for the same cultivar did not exceed 1.96 kg.

For the total fruit production (TFP), the 2 x 0.8 spacing promoted the best results, with 46.25 t ha^{-1}, and was statistically different from the other treatments. In the São Francisco Valley, the row spacing of 3 m resulted in higher yield (42.46 t ha^{-1}), while the plant spacings of 0.6 and 0.8 resulted in yields of 42.50 and 45.29 t. ha^{-1} respectively, with no significant differences between them (Ramos et al., 2012). According to Resende and Costa (2003), Cucurbitaceae plants at high densities generally produce a higher number of fruits per area. Nevertheless, the weight, size, and number of fruits per plant decreases, and the opposite is found at low densities.

As observed in Table 6, a significant difference between treatments (spacing) for the number of commercial fruits (NFC) was obtained, with no difference between treatments 1 and 3, which were statistically better than treatments 2 and 4. Batista et al. (2008) studied the same watermelon cultivar and observed that the 3.0 x 0.8 m spacing promoted a higher yield of commercial fruits. The weight of commercial fruits (AWCF) statistically as observed for the number of commercial fruits (NFC), did not statistically differ from treatments 1 and 3, which again showed better values than treatments 2 and 4. According to Oliveira *et al.* (2015), the mean fruit weight is generally a varying trait. Miranda *et al.* (2005) also evaluated different spacings on watermelon and did not observe any influence on the average fruit weight or the number of fruits per plant, however, there was a significant effect in the average weight of commercial fruits, in which the largest spacing (3.0 x 0.8 m) promoted superior results than the other treatments.

For the total production of commercial fruits (TPCF), a significant difference between the treatments was observed, and the 2 x 0.8 m spacing promoted the highest value (39.55 t ha-1). A study carried out by Ramos et al. (2009), with different spacings in watermelon, a significant effect in the commercial yield was observed, and the cultivars under the 2.0 x 0.4 m and 2.0 x 0.3 m spacings had the higher commercial yields (80.59 t ha^{-1} and 76.87 t ha^{-1}, respectively) with no significant difference between them.

For the percentage of commercial fruits (PCF), a significant difference was observed only between the treatments 3 and 4, in which T3 was statistically superior to T4. Bastos *et al.* (2008) mentions that the adequate spacing depends on the market demand. For the domestic market, a larger spacing is more suitable since it promotes the production of larger fruits. On the other hand, the foreign market demands smaller fruits.

Materials and methods

Experimental area

The experiment was carried out at the Joaquim Isac Farm, located in Granada II, Francisco Santos city, State of Piauí (06º59'34" South, 41º08'16" West and 270 m altitude) from March to May of 2016.

The total area of the experiment was 882 m^2 (70 m x 12.6 m). The useful area of the blocks was 21.6 m^2 (2.4 m x 9 m), in 32 blocks, composed of four rows.

The soil of the area was plowed with a tractor for half an hour, in which 0.3 m^3 deep pits were opened for application of 150 g dolomitic limestone 30 days before transplanting.

Edaphoclimatic conditions

The soils of the region are classified as Alluvial Eutrophic associated with Red-Yellow Latosols and tropical concretionary indiscriminate soils. according to the climate classification of Köppen and Geiger (1928), the predominant climate is tropical warm semi-arid, with a dry period of seven to eight months, rainfall distributed over two very clear periods, one rainy (summer and fall) and another dry (winter and spring) lasting seven to eight months and an annual precipitation of 781.8 mm.

Climate data for maximum and minimum temperature (ºC) and rainfall (mm) were collected daily and are presented in Figure 1.

Chemical and physical analysis of the soil

For chemical and Physics characterization of the experimental area and recommendation of limestone application, individual soil samples were collected in the 0-20 cm layer, and then mixed together in a single sample for subsequently soil Analysis at the Laboratório de Solos - LASO, at the Universidade Federal do Piauí (Table 1).

Plant materials

The cultivar 'Crimson Sweet' was chosen because it is the most appreciated in the region under study. Watermelon seeds were planted in 300 mL plastic cups containing the commercial substrate Basaplant®. Two seeds were planted per cup and thinned at V3 (when the seedling had three knots). Seedlings were transplanted 15 days after sowing in 10 cm pits that were manually opened with a small hoe.

Irrigation system

The plants were irrigated using one line of drippers per row, 0.5 m spaced. The wet areas formed by the drippers were interconnected, forming a continuous wetted area 0.4 m wide. For irrigation management, a daily watering shift and evapotranspiration values were used (ETc) according to Miranda et al. (1997), with a total irrigation depth of 270 mm between sowing and the first harvest, 3 mm daily applied. The irrigation was only used when the daily precipitation was less than 3mm.

Experimental design and treatments

A randomized complete block experimental design was used with eight replications and four treatments: T1: 3.0 m x 0.8 m; T2: 3.0m x 0.6m; T3: 2.0m x 0.8m; and T4: 2.0m x 0.6m (spacing between rows and plants, respectively), with one plant per pit.

Evaluated traits

The Growth components: plant length (PL), leaf number (LN) and stem diameter (SD) were analyzed according to the methodology proposed by Dalastra et al. (2016), leaf area (LA) according to Moreira et al. (2015), and the number of flowers (NFLO) according to Santos and Trindade (2010).

The Yield evaluations: number of fruits per plant (NFPP), average fruit weight (AFW), total fruit production (TFP), number of commercial fruits (NCF), the average weight of commercial fruits (AWCF), total weight of commercial fruits (TWCF), and percentage of commercial fruits (PCF) were evaluated according to the methodology proposed by Miranda et al. (2005).

Statistical analysis

Data were submitted to analysis of variance (ANOVA), F-test, and means were compared by Tukey's test at 5% probability. Pearson correlation was calculated for the growth traits. The Assistat software, version 7.7 beta (Silva and Azevedo, 2009) was used.

Conclusions

Watermelon plants of the cultivar 'Crimson Sweet' had better vegetative and productive performance under the plant spacing of 2.0 x 0.8 m in the microclimate of the semiarid region under study.

The study of plant population in arid and semi-arid regions is of great importance since these regions have atypical climatic conditions that should be well studied.

Studies in these regions also benefit small producers who possess small areas and depend essentially on agriculture.

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