EFFECT OF MAIZE PLANT DETASSELING ON GRAIN YIELD, TOLERANCE TO HIGH PLANT DENSITY AND DROUGHT STRESS[1]

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ABSTRACT - Maize (*Zea mays* L.) is unusually susceptible to drought and high density stresses at flowering. In part, this is related to its monoecial floral organization, which favors development of the male inflorescence, assuring pollen production and dispersion at the expense of ear and silk development. This field experiment was conducted to evaluate the potential benefits of eliminating the tassel, in terms of increasing grain yield and maize tolerance to high plant density and drought stress. Four genotypes were studied in 1993 and 1994 in Ames, IA, US. Each genotype was evaluated at the densities of 25,000 and 75,000 pl ha^{-1}. Tassel removal, either partial or total, did not significantly enhance grain yield and components, regardless of plant density or cultivar. Grain yield was higher at 75,000 pl ha^{-1} than at 25,000 pl ha^{-1} in both years. No difference in grain yield was observed between male-sterile and fertile counterparts. The absence of drought stress, and the mechanical damage to the leaves during tassel removal contributed to prevent a positive response of grain yield to tassel suppression.

Index terms: *Zea mays*, tassel, apical dominance.

EFEITO DO DESPENDOAMENTO NA PRODUÇÃO DE GRÃOS, NA TOLERÂNCIA À ALTA DENSIDADE POPULACIONAL E AO DÉFICIT HÍDRICO, EM MILHO

RESUMO - O milho (*Zea mays* L.) é bastante susceptível à deficiência hídrica e densidades de semeadura elevadas na floração. Este comportamento se deve a sua organização floral monóica, na qual o desenvolvimento da inflorescência masculina (pendão) é favorecido sob condições de estresse, garantindo produção e dispersão de pólen, às custas do desenvolvimento da espiga e dos estigmas. Este trabalho foi conduzido em Ames, Iowa, E.U.A., durante os anos agrícolas de 1993 e 1994, com o objetivo de verificar virtuais benefícios da eliminação do pendão no tocante ao rendimento de grãos, à tolerância da cultura ao estresse hídrico e à tolerância a alta densidade da população das plantas. Quatro genótipos foram estudados por estação de crescimento. Cada genótipo foi avaliado nas densidades de 25.000 e 75.000 pl. ha^{-1}, com pendões intactos, parcialmente ou totalmente removidos. A remoção parcial ou total do pendão não aumentou o rendimento de grãos e componentes de produção do milho, independentemente de cultivar ou densidade das plantas. O rendimento de grãos foi maior a 75.000 pl. ha^{-1} do que a 25.000 pl. ha^{-1}, em ambos os anos. Nenhuma diferença em rendimento foi observada entre genótipos férteis e macho-estéreis. A ausência de estresse hídrico e o dano mecânico causado às folhas superiores durante a remoção do pendão diminuíram virtuais benefícios do despendoamento quanto ao rendimento de grãos.

Termos para indexação: *Zea mays*, pendão, dominância apical.

INTRODUCTION

Among the economically important grasses, only maize flowers monoeciously, having its staminate inflorescence located at the apex of the plant and the pistillate inflorescence at the apex of axillary branches (Cheng & Paredy, 1994). The differences between

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apical and axillary inflorescences in location, timing of differentiation and development may promote competition for resources, particularly under stress conditions. Apical structures usually have preferential use of the resources available to the plant, more specifically, water, nutrients and photosynthates (Paterniani, 1981). Because of this, the tassel has developmental priority over the ears of the same plant.

The net result of this pattern is a protandrous behavior assuring that under adverse situations there will be pollen production and dispersion, but at the expense of ear and silk development (Jensen, 1971; Hall et al., 1982; Westgate & Basseti, 1991). Since maize has a short period of flowering, and pollen remains viable for only a brief period of time, each day of delay between pollen shed and silk emergence translates into a reduction in the rate of sexual fertilization, an increase in barrenness, and a decrease in yield.

Given the apical dominance of tassel over ears, and the problem of asynchronous flowering that affects corn yield under stressful conditions, an ideotype of maize has been proposed by Sangoi (1996) to increase drought tolerance. A unique anatomical and morphological feature proposed in this model phenotype is the transfer of the site of grain production from the apex of a lateral branch to the apex of the main stem. The basic assumption underlying this feature is that the suppression of the tassel and the production of grains at the apex of the main stem would remove the susceptibility of grains to apical dominance, as well as the dependence of conventional maize on favorable water status during the narrow interval between pollen-shed and silking.

Aside from establishing a breeding program to develop a plant where the male inflorescence is replaced by an apical ear, it is important to evaluate the actual degree of physiological competition between the tassel and the ear, as well as the supposed benefits to grain production of eliminating the male inflorescence. One way to accomplish that goal is by removing the tassel mechanically before anthesis.

There is a history of more than 100 years of experimentation to evaluate the effects of detasseling on maize grain production, beginning in the previous century with Watson (1892) and continuing to the present (Wilhelm et al., 1995). The monoecious nature of the corn plant and the apical location of the tassel make it relatively easy to mechanically remove this inflorescence at various stages of its development.

Tassel removal at or near anthesis has given a wide range of results over the years. Grogan (1956), Chinwuba et al. (1961) , Schwanke (1965), Hunter et al. (1969) and Mosterd & Marais (1982) observed improvements in grain yield due to elimination of the male inflorescence before pollination. Morrow & Gardner (1892) and Leonard & Kiesselbach (1932) found no effect on yield from tassel removal. On the other hand, Dungan & Woodworth (1939), Kiesselbach (1945) Hunter et al. (1973) and Wilhelm (1995) reported reductions in grain yield and kernel mass, particularly when leaves were removed with tassels.

Most of the information generated from experiments with tassel removal was obtained through a period ending approximately 20 years ago. However, corn hybrids have been greatly improved through breeding in the last three decades. In general, newer hybrids attain higher grain yields than older materials particularly under high densities and other stress conditions (Russell, 1991; Duvick, 1994).

Given the lack of data on the effect of detasseling for midwestern hybrids and inbreds developed in the 80s and 90s, and taking into account that several agronomic traits, including grain yield, have been continuously modified by breeders in recent years, an experiment was designed to evaluate the response to detasseling of adapted midwestern inbreds and hybrids sown at two plant densities.

The purpose of the study was to test whether improved grain yield, tolerance to high plant density, and to drought stresses would result from the absence of the tassel.

MATERIAL AND METHODS

The study was conducted during the growing seasons of 1993 and 1994, in Ames, IA, United States. The climate of the region is classified as Dfa, cold with a moist winter and a hot summer. Study site soil is a Nicollet loam (Fine--loamy, mixed, mesic Aquic Hapludoll).

A factorial treatment design was used, with a combination of three factors: cultivar, plant population and level of detasseling. The experimental design was a split-split plot with the main plots arranged in a randomized complete block and with four replications for each treatment. The main plot consisted of four different genotypes. In 1993 one inbred and three hybrids were evaluated. The hybrids tested that year were: NK 4525, CP 8032, and CP 8364. All materials evaluated in 1993 were male-fertile. In 1994 one inbred and one hybrid (NK 6330) were analyzed. For both materials, a sterile version plus its fertile counterpart were included in the trial. The source of male-sterility used in the sterile version was the S cytoplasm.

Each genotype was evaluated at two plant populations in the split-plot. The populations used were equivalent to 25,000 and 75,000 pl ha^{-1}. Three levels of detasseling were tested in the split-split plot. In level 1, tassels were kept intact; in level 2, tassels were entirely removed; in level 3, approximately half of the tassel branches was removed. Partial detasseling was effected by first counting the total number of branches presented and removing half of these. Tassels were eliminated partially or totally as soon as it was possible to reach them inside the whorl, when plants were between V16 and V17 (Ritchie & Hanway, 1982).

Each split-split plot consisted of three rows, spaced 0.75 m equidistantly. Individual plot rows were 6 m long. In the detasseling treatments, tassels were pulled out only in the central row of the plot.

Fertilizer was applied according to soil test recommendations from the ISU soil testing laboratory. The experiments were hand-planted on 15 May 1993 and 3 May 1994. Three seeds were dropped per hill to assure the desired stand on each treatment. When plants were at stage V4, thinning was performed to adjust the population to desired levels. Plots were also hand-hoed and wheel-hoed to control weed competition. 80 kg ha^{-1} of elemental N were side-dressed at V7 in 1993. No side-dressed nitrogen was necessary in 1994.

Harvesting was performed by hand on October 16, 1993, and September 28, 1994, after leaves had senesced entirely. Only the central row of each split-split plot was harvested. Ears were dehusked and shelled, kernels were weighed once they achieved uniform moisture. The value obtained was transformed for an area of one hectare and adjusted to a standard moisture of 15.5%. After weighing kernels from a whole plot, a sub sample of 200 grains was re-weighed. This value was multiplied by 5 to express the final weight of 1000 grains reported in the experiment. The number of grains produced for each ear was evaluated indirectly by finding the relationship between weight of 200 grains, weight of total number of kernels, and the number of ears harvested from each split-split plot. Number of ears per plant was determined by dividing number of harvested ears by number of harvested plants.

Analysis of variance was performed using the General Linear Models procedure of the Statistical Analysis System (SAS), version 6.07 for Unix Systems (SAS Institute, 1987). F values for main treatment effects and their interactions were considered significant at the $P<0.05$ level. Whenever a particular factor or interaction of factors significantly influenced a variable, means were separated using Fischer's LSD test at the 0.05 probability level, following methodology dscribed in Little & Hills (1978).

RESULTS AND DISCUSSION

In 1993, grain yield was significantly affected by cultivar, plant density and the interaction between plant density and level of detasseling. Hybrid CP 8364 yielded the best and the inbred the lowest (Table 1). When planted in a population of 75,000 pl ha^{-1}, cultivars averaged 67% greater yield than when sown at 25,000 pl ha^{-1}. No effect of detasseling was observed on grain yield at the lower plant population (Table 2). However, partial elimination of the tassel negatively impacted grain yield at 75,000 pl ha^{-1}. At both plant densities, tassel elimination, either total or partial, did not improve grain yield significantly, regardless of cultivar used.

An interaction between plant density and levels of detasseling was also associated with the variation

TABLE 1. Grain yield (kg ha^{-1}) of four corn cultivars at two plant densities, Ames, Iowa, 1993[1].

Genotype	Plant density (pl ha^{-1})		
	25,000	75,000	Mean
Inbred	2,021	4,039	3,030c
CP 8032	5,302	7,692	6,497b
CP 8364	5,512	9,630	7,571a
NK 4525	4,781	8,190	6,485b
Mean	B 4,404	A 7,388	5,896

Means of three levels of detasseling; means followed by the same lower--case letter in the column or preceded by the same capital letter in the row are not significantly different by the LSD test (P = 0.05); LSD cultivar means = 732 kg ha^{-1}; LSD plant population means = 958 kg ha^{-1}.

observed in number of grains produced per ear in 1993 (Table 2). Tassel removal had no impact on this variable at 25,000 pl ha^{-1}. However, at 75,000 pl ha^{-1} number of kernels per ear was significantly lower when half of the tassel was removed as compared with complete detasseling. The decrease in the number of viable grains per ear induced by partial detasseling at higher plant density contributed to the lower grain yield observed when this combination of treatments was performed in 1993.

TABLE 2. Effects of levels of detasseling on grain yield (kg ha^{-1}) and number of grains per ear of corn cultivars at two plant densities, Ames, Iowa, 1993[1].

Levels of detasseling	Plant density (pl ha^{-1})	
	25,000	75,000
	--------- Grain yield ---------	
None	B 4,086a	A 7,774a
Partial	B 4,460a	A 6,438b
Total	B 4,667a	A 7,951a
	------- Grains per ear -------	
None	A 531a	B 484ab
Partial	A 559a	B 459b
Total	A 536a	B 493a

Means of four genotypes; means followed by the same lower-case letter in the column or preceded by the same capital letter in the row are not significantly different by the LSD test (P = 0.05); LSD plant density means within each level of detasseling for grain yield = 944 kg ha^{-1}; LSD levels of detasseling means within each level of plant density for grain yield = 800 kg ha^{-1}; LSD plant density means within each level of detasseling for grains per ear = 39; LSD levels of detasseling means within each level of plant density for grains per ear = 32.

Average yields in 1994 were greater than in the previous year (Table 3). As expected, hybrids produced significantly greater yield per area than inbreds. Male-sterile cytoplasm promoted small yield increments, in relation to fertile counterparts. However, differences were not statistically significant at the level of 5% of probability. Grain yield per hectare was 67% greater at 75,000 pl ha^{-1} than at 25,000 pl ha^{-1}. Regardless of the cultivar or plant density used, detasseling did not significantly affect grain yield in 1994. Averaged across plant densities and cultivars, plots with tassels produced 9,205 kg ha^{-1}, while treatments with some kind of tassel removal produced 9,127 kg ha^{-1}.

In 1993, there was significant interaction between cultivar and plant density as measured by number of ears produced per plant. At 25,000 pl ha^{-1}, hybrids CP 8364 and NK 4525 were more prolific than the other materials (Table 4). Hybrids with the greatest number of ears per plant at the low population were also those that showed the greatest reduction in this variable with increase in population. Therefore, within the highest population level, there was no difference among cultivars with regard to number of ears per plant. In 1993, cultivars varied in number of grains produced per ear according to plant population (Table 4). Hybrid CP 8032 was most sensitive to increment in plant density, producing less grains per ear at 75,000 pl ha^{-1} than at 25,000 pl ha^{-1}. Hybrid CP 8364 showed the greatest number of grains per ear at both plant densities, accounting for its higher grain yield per area (Tables 1 and 4). In contrast, the inbred showed the lowest number of grains per ear at both plant densities.

TABLE 3. Effect of plant density on the grain yield (kg ha^{-1}) of two inbreds and two hybrids of corn, Ames, Iowa, 1994[1].

Plant density (pl ha^{-1})	Genotype				
	Inbred sterile	Inbred fertile	Hybrid sterile	Hybrid fertile	Mean
25,000	4,448	4,024	9,243	9,669	6,846b
75,000	8,533	8,300	14,794	14,215	11,461a
Mean	B 6,490	B 6,162	A 12,018	A 11,942	9,153

[1] Means of three levels of detasseling; means followed by the same lower-case letter in the column or preceded by the same capital letter in the row are not significantly different by the LSD test (P=0.05); LSD genotype means = 627; LSD plant density means = 630.

Increase in plant population from 25,000 to 75,000 pl ha^{-1} induced a significant decrease in weight of 1000 grains of all materials in 1993 (Table 4). This decrease was greater for hybrid CP 8032, which had the highest weight of 1000 grains at the lower population. At both plant populations, CP 8364 and the inbred had the lightest kernels. Cultivars also reacted differently to the level of detasseling imposed during the first growing season (Table 5). Partial removal of the tassel promoted a decrease in kernel weight of hybrid CP 8032. In contrast, weight of 1000 grains of the other three materials was not affected by level of detasseling.

In 1994 the only significant differences observed among treatments in terms of grains per ear and ears per plant were due to cultivar and plant density effects. Hybrids produced more ears per plant and grains per ear than inbreds (Table 6). Cytoplasmatic male sterility had no effect on those variables.

Hybrids produced heavier grains than inbreds in 1994, regardless of plant population tested (Table 7). Introduction of a sterile cytoplasm did not significantly change the weight of 1000 grains for the hybrid. Lack of viable pollen production stimulated formation of heavier grains for the inbred, particularly at the higher plant population. Also, the sterile version of the inbred was able to tolerate the

TABLE 4. Effect of plant density on yield components of four corn cultivars, Ames, Iowa, 1993[1].

Plant density (pl ha^{-1})	Genotype			
	Inbred	CP 8032	CP 8364	NK 4525
	Ears per plant			
25,000	B 0.96a	B 1.00a	A 1.33a	A 1.40a
75,000	A 0.92a	A 0.95a	A 1.01b	A 0.96b
	Grains per ear			
25,000	C 331a	A 624a	A 684a	B 530a
75,000	C 328a	B 465b	A 628a	B 493a
	Weight of 1000 grains (g)			
25,000	C 245a	A 345a	C 252a	B 282a
75,000	C 196b	A 248b	B 217b	A 264b

Means of three levels of detasseling; means followed by the same lower-case letter in the column or preceded by the same capital letter in the row, for each variable, are not significantly different by the LSD test (P=0.05); LSD genotype means within each level of plant density for ears per plant = 0.20; LSD plant density means within each level of genotype for ears per plant = 0.21; LSD genotype means within each level of plant density for grains per ear= 85; LSD plant density means within each level of genotype for grains per ear = 59; LSD genotype means within each level of plant density for weight of 1000 grains = 21; LSD plant density means within each level of genotype for weight of 1000 grains = 14.

TABLE 5. Effect of levels of detasseling on the weight of 1 000 grains (g) of four corn cultivars, Ames, Iowa, 1993[1].

Level of detasseling	Genotypes			
	Inbred A	CP 8032	CP 8364	NK 4525
None	C 218a	A 309a	C 232a	B 277a
Partial	B 220a	A 278b	B 231a	A 268a
Total	C 223a	A 303a	C 240a	B 275a

Means of two plant densities; means followed by the same lower-case letter in the column or preceded by the same capital letter in the row are not significantly different by the LSD test (P = 0.05); LSD genotype means within each level of detasseling = 20; LSD detasseling means within each level of genotype = 10.

TABLE 6. Yield components of four corn genotypes, Ames, Iowa, 1994[1].

Genotype	Yield components		
	Ears per plant	Grains per ear	Weight of grains (g)
Inbred sterile	1.18b	369b	119b
Inbred fertile	1.17b	386b	117b
Hybrid sterile	1.26a	581a	221a
Hybrid fertile	1.29a	561a	219a

[1] Means of two plant densities and three levels of detasseling; means followed by the same letter in each column are not significantly different by the LSD test (P = 0.05); LSD genotype means for ears per plant = 0.09; LSD genotype means for grains per ear = 41; LSD genotype means for weight of grains = 14.

TABLE 7. Effect of plant density on the weight of 1000 grains (g) of two inbreds and hybrids of corn, Ames, Iowa, 1994[1].

Plant density (pl ha^{-1})	Genotype			
	Inbred sterile	Inbred fertile	Hybrid sterile	Hybrid fertile
25 000	B 330a	B 316a	A 407a	A 414a
75 000	C 317a	B 297b	A 362b	A 363b

[1] Means of three levels of detasseling; means followed by the lower-case letter in the column or preceded by the same capital letter in the row are not significantly different by the LSD test (P = 0.05); LSD genotype means within each level of plant density =19; LSD plant density means within each level of cultivar = 16.

increase in plant population without significantly decreasing the weight of 1000 kernels, which did not happen with its fertile counterpart. When averaged across cultivars and plant densities, partial detasseling was detrimental to weight of 1000 grains. Weight of 1000 grains was 3.0% lower when tassels were removed than when tassels were intact.

The initial premise that mechanical removal of the male inflorescence before anthesis would reduce apical dominance and promote higher grain yield, particularly at high plant density, was not supported by the results of this experiment. In both years, there was no significant advantage to grain yield from detasseling when compared to plants with intact inflorescence. This result differs from those reported by Grogan (1956), Chinwuba et al. (1961), Schwanke (1965), Hunter et al. (1969) and Mosterd & Marais (1982), who observed grain yield increase when tassels were removed before pollination.

Failure of grain yield to respond positively to tassel removal was a result of many factors. The final impact of tassel removal on grain yield depends on the climatic and edaphic conditions of the experimental site, plant population, cultivar used, time of detasseling and amount of leaf damage during the operation. Generally speaking, tassel removal tends to improve yield under conditions of high plant density, moisture stress and nutritional deficiency, a trend that is more perceptible in cultivars that naturally produce large tassels. Therefore, the response of grain yield to detasseling is likely to be lower under favorable environments, low plant population, late removal of the inflorescence, in cultivars that are male-sterile or that produce small tassels or which have been selected for high plant populations.

Apical dominance of the tassel over the ear is usually accentuated under conditions of high temperature and low moisture. There was no significant water deficit in either year of the study. In addition, temperatures during the summer months were below normal most of the time. Hence, one factor possibly mitigating the potential beneficial effect of tassel removal on yield is that environmental conditions were not appropriate for induction of protandry. The cool temperatures and lack of a significant drought pressure decreased the likelihood of competition between the apical and axillary inflorescences, minimizing possible benefits of detasseling.

The fertility level of the soil used in the experiment was quite high. The amounts of P and K present in the soil before the installation of the trial each year were above those considered adequate for maize growth. Also, substantial amounts of N were incorporated into the soil before planting each growing season. Thus, it was not very likely that nutrient supply was limiting during any part of the growth cycle, a condition also potentially minimizing the impact of apical dominance. The same effect was reported by Grogan (1956), who did not observe any significant increase in grain yield when detasseling was performed during a season of normal rainfall and on a fertile soil.

In the present study, two contrasting plant densities were chosen: one below and the other above the optimum range recommended by Larson (1994) for a normal year in Central Iowa. Greater than optimum populations stimulate apical dominance, which is usually reflected as increased barrenness (Olson & Sanders, 1988). The expectation was to observe the greatest grain yields with tassel removal at 75,000 pl ha^{-1}. However, this did not occur. It is possible that the population of 75,000 pl ha^{-1} was not high enough to induce a sufficient competition between tassel and ears under the conditions of this experiment. Duncan (1958), Meyer (1970) and Tollenaar (1992) note that as fertility status and moisture of the soil improves, plant density required to elicit maximum yield by maize is also increased. Therefore, the environmental and edaphic conditions of both growing seasons might have been favorable enough to lift the optimum population to maximize yield, preventing a possible positive response to detasseling at the high density chosen for the experiment.

Barrenness promoted by apical dominance or for any other reason is a manifestation of an individual plant response to a given set of environmental conditions. Remarkable variability in the response of a corn plant to increasing plant population has been reported in the literature. Overall, one of the most prominent differences observed between the hybrids cultivated in the 90s and the materials used in the 50s and 60s, when most of the detasseling experiments found in the literature were conducted, is the greater ability of the new cultivars to withstand higher plant populations, resulting in fewer barren plants. This pattern has been consistently demonstrated by Russell (1991), Tollenaar (1992), Duvick (1994). The genotypes used in this experiment were not selected on the basis of their capacity to withstand high planting rates, but rather on the basis of availability of seeds and fertile and sterile versions of an specific inbred or hybrid (in the second year). Lack of positive grain yield response to detasseling may be related to the genetic ability of the materials used in the experiment to tolerate high plant populations, reducing the potential benefit of detasseling.

Another possibility to explain why tassel removal did not improve grain yield is that the possible benefits of detasseling may have been offset by some negative consequences of such a practice. Mechanical detasseling may be detrimental to the maize plant in three different ways: by damaging the upper leaves; by stimulating disease infections; by depriving the crop of pollen (Kiesselbach, 1945). In the present experiment, no significant increase in smut incidence was observed in detasseled plots. The lack of viable pollen for fertilization also does not appear to have been a negative hazard of detasseling on yield because only the central row of the plot was detasseled. However, the unintentional removal or damage of the younger unfolded leaves along with the tassel may have contributed to the results reported herein.

Wilhelm et al. (1995) reported a linear decline in grain and stover yield with number of leaves removed with the tassel. Each leaf removed reduced grain yield about 0.36 Mg ha^{-1}, which was caused mainly by decreasing kernel size. Dungan & Woodworth (1939) and Hunter et al. (1973) also reported reductions in grain yield and kernel mass when leaves were damaged during detasseling. In both years of the study, tassels were pulled out when at least three leaves were not totally unfolded. The purpose was to eliminate the tassel as early as possible to accentuate the benefits of detasseling. Nonetheless, it turned out that it was very difficult to perform detasseling at V16 without causing some damage to the plant. The level of difficulty was apparently greater for those plots that were partially detasseled because in those cases the young leaves that were unfolded had to be forced open so that the number of branches could be estimated before removing half of them . This task was particularly difficult at the 75,000 pl ha^{-1} population, where plants were taller, had smaller tassels and were closer to each other. The greater amount of leaf injury, specially at the high plant populations and in the treatments where only half of the inflorescence was removed, is probably the most logical explanation for the decreases on grain yield and number of grains per ear observed when partial removal was performed (Table 2). Possibly, it would have been more appropriate to wait 4-5 more days to remove the tassels closer to their emergence from the whorl as it was observed by Schwanke (1965).

CONCLUSIONS

1. Tassel removal does not enhance maize grain yield and components, regardless of cultivar or plant density.

2. Lack of drought stress and mechanical damage to the leaves mitigate benefits of detasseling to grain yield.

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