THE COMBINED USE OF CHEMICAL AND ORGANIC FERTILIZERS AND/OR BIOFERTILIZER FOR CROP GROWTH AND SOIL FERTILITY

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Abstract

Plant nutrients are essential for the production of crops and healthy food for the world's expanding population. Plant nutrients are therefore a vital component of sustainable agriculture. Increased crop production largely relies on the type of fertilizers used to supplement essential nutrients for plants. The nature and the characteristics of nutrient release of chemical, organic and biofertilizers are different, and each type of fertilizer has its advantages and disadvantages with regard to crop growth and soil fertility. The sound management of fertilization must attempt to ensure both an enhanced and safeguarded environment; therefore, a balanced fertilization strategy that combines the use of chemical, organic or biofertilizers must be developed and evaluated.

Introduction

For optimum plant growth, nutrients must be available in sufficient and balanced quantities. Soils contain natural reserves of plant nutrients, but these reserves are largely in forms unavailable to plants, and only a minor portion is released each year through biological activity or chemical processes. This release is too slow to compensate for the removal of nutrients by agricultural production and to meet crop requirements. Therefore, fertilizers are designed to supplement the nutrients already present in the soil. The use of chemical fertilizer, organic fertilizer or biofertilizer has its advantages and disadvantages in the context of nutrient supply, crop growth and environmental quality. The advantages need to be integrated in order to make optimum use of each type of fertilizer and achieve balanced nutrient management for crop growth.

The rhizosphere of the soil–plant system

The rhizosphere is the zone of soil surrounding the root which is affected by it. The significance of the rhizosphere arises from the release of organic material from the root and the subsequent effect of increased microbial activity on nutrient cycling and plant growth. In the rhizosphere the quantities and the types of substrates are different from those in the bulk soil and this leads to colonization by different populations of bacteria, fungi, protozoa and nematodes. Other physicochemical factors which can be different in this region are acidity, moisture and nutrient status, electrical conductivity and redox potential. The association between organisms and roots can be beneficial (water uptake, soil stabilization, growth promotion, N_2 fixation, biocontrol, antibiosis, symbiosis), harmful (infection, phytoxicity) or neutral (nutrient flux, free enzyme release, attachment, alleopathy, competition) — these effects often depend on soil conditions and therefore must be regarded as variable. Interactions that are beneficial to agriculture include mycorrhizae, legume nodulation and production of antimicrobial compounds that inhibit the growth of pathogens. Clearly the goal in manipulating the rhizosphere must be to increase the balance of beneficial effects as the rhizosphere is deeply affected by fertilization.

Keywords: plant nutrients, sustainable agriculture, balanced fertilization strategy, supplement essential nutrient, biofertilizer

The advantages and disadvantages of using chemical and organic fertilizers for crop growth and soil fertility

Among the materials used in agriculture, fertilizer is the most widely used. Based on the production process, it can be roughly categorized into three types: chemical, organic and biofertilizer. Each type of fertilizer has its advantages and disadvantages. These advantages need to be integrated in order to achieve optimum performance by each type of fertilizer and to realize balanced nutrient management for crop growth.

The advantages of using chemical fertilizers

1. Nutrients are soluble and immediately available to the plants; therefore the effect is usually direct and fast.
2. The price is lower and more competitive than organic fertilizer, which makes it more acceptable and often applied by users.
3. They are quite high in nutrient content; only relatively small amounts are required for crop growth.

The disadvantages of using chemical fertilizers

1. Overapplication can result in negative effects such as leaching, pollution of water resources, destruction of micro-organisms and friendly insects, crop susceptibility to disease attack, acidification or alkalization of the soil or reduction in soil fertility — thus causing irreparable damage to the overall system.
2. Oversupply of N leads to softening of plant tissue resulting in plants that are more sensitive to diseases and pests.
3. They reduce the colonization of plant roots with mycorrihizae and inhibit symbiotic N fixation by rhizobia due to high N fertilization.
4. They enhance the decomposition of soil OM, which leads to degradation of soil structure.
5. Nutrients are easily lost from soils through fixation, leaching or gas emission and can lead to reduced fertilizer efficiency.

The advantages of using organic fertilizers

1. The nutrient supply is more balanced, which helps to keep plants healthy.
2. They enhance soil biological activity, which improves nutrient mobilization from organic and chemical sources and decomposition of toxic substances.
3. They enhance the colonization of mycorrhizae, which improves P supply.
4. They enhance root growth due to better soil structure.
5. They increase the organic matter content of the soil, therefore improving the exchange capacity of nutrients, increasing soil water retention, promoting soil aggregates and buffering the soil against acidity, alkalinity, salinity, pesticides and toxic heavy metals.
6. They release nutrients slowly and contribute to the residual pool of organic N and P in the soil, reducing N leaching loss and P fixation; they can also supply micronutrients.
7. They supply food and encourage the growth of beneficial micro-organisms and earthworms.
8. They help to suppress certain plant diseases, soil-borne diseases and parasites.

The disadvantages of using organic fertilizers

1. They are comparatively low in nutrient content, so larger volume is needed to provide enough nutrients for crop growth.
2. The nutrient release rate is too slow to meet crop requirements in a short time, hence some nutrient deficiency may occur.

3. The major plant nutrients may not exist in organic fertilizer in sufficient quantity to sustain maximum crop growth.
4. The nutrient composition of compost is highly variable; the cost is high compared to chemical fertilizers.
5. Long-term or heavy application to agricultural soils may result in salt, nutrient or heavy metal accumulation and may adversely affect plant growth, soil organisms, water quality and animal and human health.

The role of biofertilizers in crop production

Soil micro-organisms play a significant role in regulating the dynamics of organic matter decomposition and the availability of plant nutrients such as N, P and S. It is well-recognized that microbial inoculants constitute an important component of integrated nutrient management that leads to sustainable agriculture. In addition, microbial inoculants can be used as an economic input to increase crop productivity; fertilizer doses can be lowered and more nutrients can be harvested from the soil. Biofertilizer is defined as a substance which contains living micro-organisms and is known to help with expansion of the root system and better seed germination. A healthy plant usually has a healthy rhizosphere which should be dominated by beneficial microbes. Conversely, in unhealthy soil, dominated by pathogenic microbes, optimum plant growth would not be possible.

Biofertilizers differ from chemical and organic fertilizers in the sense that they do not directly supply any nutrients to crops and are cultures of special bacteria and fungi. The production technology for biofertilizers is relatively simple and installation cost is very low compared to chemical fertilizer plants.

The main micro-organisms used as biofertilizers and their functions

Rhizobia

Rhizobia are symbiotic bacteria that fix atmospheric N_2 gas in plant root nodules and have a mutually helpful relationship with their host plants. The plant roots supply essential minerals and newly synthesized substances to the bacteria. Because of their N-fixing ability, legumes are less reliant on inorganic N fertilizer than many other non-legume crops such as cereals and pasture grasses. N fixation by legumes can also maintain soil fertility and can be of benefit to the following crop. Rhizobium inoculation is a well-known agronomic practice to ensure adequate N supply for legumes in place of N fertilizer. It is reported that rhizobium can fix 50-300 kg N/ha. Heavier application of inoculums mixed into peat granules trickled into soil as the seeds are planted is an alternative technique to encourage nodulation.

Azotobacters and azospirillum

These are free-living bacteria that fix atmospheric nitrogen in cereal crops without any symbiosis and they do not need a specific host plant. Azotobacters are abundant in well-drained, neutral soil. They can fix 15-20 kg/ha N per year. *Azotobacter* sp. can also produce antifungal compounds to fight against many plant pathogens. They also increase germination and vigour in young plants leading to improved crop stands.

Phosphate-solubilizing bacteria (PSB)

Under acidic or calcareous soil conditions, large amounts of phosphorus are fixed in the soil but are unavailable to the plants. Phosphobacterins, mainly bacteria and fungi, can make insoluble phosphorus available to the plant. The solubilization effect of phosphobacterins is generally due to the production of organic acids that lower the soil pH and bring about the dissolution of bound forms of phosphate. It is reported that PSB culture increased yield up to 200-500 kg/ha and thus 30 to 50 kg of superphosphate can be saved.

Vesicular arbuscular mycorrhiza (VAM)

Mycorrhizae are mutually beneficial (symbiotic) relationships between fungi and plant roots. VAM fungi infect and spread inside the root. They possess special structures known as vesicles and arbuscules. The plant roots transmit substances (some supplied by exudation) to the fungi, and the fungi aid in transmitting nutrients and water to the plant roots. The fungal hyphae may extend the root lengths 100-fold. The hyphae reach into additional and wetter soil areas and help plants absorb many nutrients, particularly the less available mineral nutrients such as phosphorus, zinc, molybdenum and copper. Some VAM fungi form a kind of sheath around the root, sometimes giving it a hairy, cottony appearance. Because they provide a protective cover, mycorrhizae increase seedling tolerance to drought, to high temperatures, to infection by disease fungi and even to extreme soil acidity. Application of VAM produces better root systems which combat root rotting and soil-borne pathogens. The greatest growth response to mycorrhizal fungi is probably in plants in highly weathered tropical acid soils that are low in basic cations and P, and may have toxic levels of aluminium. Plants that have coarse or limited root systems should benefit the most.

Plant growth promoting rhizobacteria (PGPR)

PGPR represent a wide variety of soil bacteria which, when grown in association with a host plant, result in stimulation of host growth. PGPR modes include fixing N_2, increasing the availability of nutrients in the rhizosphere, positively influencing root growth and morphology and promoting other beneficial plant–microbe symbioses. Some researchers have indicated that PGPR will often have multiple modes of action. Ratti *et al*. (2001) found that a combination of the arbuscular mycorrhizal fungi *Glomus aggregatum*, the PGPR *Bacillus polymyxa* and *Azospirillum brasilense* maximized biomass and P content of the aromatic grass palmarosa (*Cymbopogon martinii*) when grown with an insoluble inorganic phosphate.

Inoculation of biofertilizers

Biofertilizers are generally applied to soil, seeds or seedlings, with or without some carrier for the micro-organisms, for example, peat, composts or stickers. Regardless of methods, the number of cells reaching the soil from commercial products is smaller than the existing numbers of soil or rhizosphere micro-organisms; these added cells are unlikely to have a beneficial impact on the plant unless multiplication occurs. In addition, the population of introduced micro-organisms will decline and be eliminated in a very short time, often days or weeks. The formulation of inoculums, method of application and storage of the product are all critical to the success of a biological product. Short shelf life, lack of suitable carrier materials, susceptibility to high temperature, problems in transportation and storage are biofertilizer bottlenecks that still need to be solved in order to obtain effective inoculation.

Seed inoculation

Seed inoculation uses a specific strain of microbe that can grow in association with plant roots; soil conditions have to be favourable for the inoculants to perform well. Selected strains of N-fixing Rhizobium bacteria have proven to be effective as seed inoculants for legumes.

The seed treatment can be done with any of two or more bacteria without antagonistic effect. In the case of seed treatment with Rhizobium, Azotobacter, Azospirillum along with PSB, first the seeds must be coated with Rhizobium or Azotobacter or Azospirillum. When each seed has a layer of the aforesaid bacteria then the PSB inoculant has to be treated on the outer layer of the seeds. This method will provide maximum numbers of population of each bacterium to generate better results.

Soil inoculation

In soil inoculation, microbes are added directly to the soil where they have to compete with microbes already living in the soil that are already adapted to local conditions and greatly outnumber the inoculums. Inoculants of mixed cultures of beneficial micro-organisms have considerable potential for controlling the soil microbiological equilibrium and providing a more favourable environment for plant growth and protection. Therefore, adequate quality control and a high level of consistency in performance and benefits must be ensured.

Although inoculations with PSBs have not been very effective, joint inoculation of PSBs with mycorrhizae and N_2-fixing bacteria have been successful. Co-inoculation of Azospirillum, Rhizobium and

Combined use of different fertilizers

Combined use of chemical and organic fertilizers

There is increased emphasis on the impact on environmental quality due to continuous use of chemical fertilizers. The integrated nutrient management system is an alternative and is characterized by reduced input of chemical fertilizers and combined use of chemical fertilizers with organic materials such as animal manures, crop residues, green manure and composts. Management systems that rely on organic inputs as plant nutrient sources have different dynamics of nutrient availability from those involving the use of chemical fertilizers. For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer. A field experiment was conducted by Chand *et al.* (2006) for seven years continuously to evaluate the influence of combined applications and organic and chemical fertility buildup and nutrient uptake in a mint (*Mentha arvensis*) and mustard (*Brassica juncea*) cropping sequence. Results indicated that integrated supply of plant nutrients through FYM (farmyard manure) and fertilizer NPK, along with *Sesbania* green manuring, played a significant role in sustaining soil fertility and crop productivity. Based on the evaluation of soil quality indicators, Dutta *et al.* (2003) reported that the use of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health. Application of organic manure in combination with chemical fertilizer has been reported to increase absorption of N, P and K in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone (Bokhtiar & Sakurai 2005).

Kaur *et al.* (2005) compared the change of chemical and biological properties in soils receiving FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for seven years under a cropping sequence of pearl millet and wheat. Results showed that all treatments except chemical fertilizer application improved the soil organic C, total N, P, and K status. Increase in microbial biomass C and N was observed in soils receiving organic manures only or with the combined application of organic manures and chemical fertilizers compared to soils receiving chemical fertilizers. This study showed that balanced fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter (OM) content and long-term soil productivity in the tropics where soil OM content is low.

The effects of organic fertilization and combined use of chemical and organic fertilizer on crop growth and soil fertility depends on the application rates and the nature of fertilizers used. In general, the application rates of organic fertilizer mostly are based on crop N need and estimated rates of organic fertilizer N supply, but do not consider the amount of P and K provided with organic fertilizer. However, the N/P ratio of organic fertilizer usually is significantly lower than the N/P uptake ratio of the crop. Therefore, basing organic fertilizer on N supply typically results in P addition in excess of the crop's need. Nutrients, salt or heavy metal accumulation has also been reported in many papers , especially for the long-term or heavy use of organic fertilizers with higher contents of P, K, salt, or heavy metals.

An experiment was conducted to evaluate the fertilization strategy on cabbage (*Brassica oleracea* L. cultivar early autumn) growth, nutrient availability and nutrient accumulation in a strongly acidic soil (Tzen & Chen 2004). Five treatments — check (CK), chemical fertilizer (CF), N-based application rate of composted animal manure (Compost-N), P-based application of composted animal manure (Compost-P) and combined with a P-based application of composted animal manure with urea supplement (Compost-P + urea) — were selected to compare their effects. In addition, fertilizers for each treatment were only applied for the first crop (cabbage) and not for the second crop (maize). Results showed that the yield of cabbage in all treatments with compost addition was higher than that of the CF treatment, but Compost-N , and Compost-P + urea treatments showed their residual effect compared to CF treatment (Table 1). However, the relative yield of cabbage in the Compost-P treatment was lower than that of the CF treatment, indicating that the application of compost based on the P need of cabbage could not provide enough N for cabbage use; but if urea was used to supplement deficient N (for example, Compost-P + urea), cabbage was growth increased and the accumulation of nutrients (Bray-1 P and exchangeable K in the soil) was lessened. It suggested that P-based compost application with the urea supplement was the best fertilizer management strategy for the soil and would avoid the accumulation of nutrients, salt and heavy metals.

Combined use of biofertilizers with chemical or organic fertilizers

The activity of soil organisms is very important for ensuring sufficient nutrient supply to the plant. If the micro-organisms find suitable conditions for their growth, they can be very efficient in dissolving nutrients and making them available to plants. Sundara *et al.* (2002) found that the application of PSB, *Bacillus megatherium* var. *phosphaticum*, increased the PSB population in the rhizosphere and P availability in the soil. It also enhanced sugarcane growth, yield and quality. When used in conjunction with P fertilizers, PSB reduced the required P dosage by 25%. In addition, 50% of costly superphosphate could be replaced by a cheap rock phosphate, when applied in combination with PSB.

The effects of a combined treatment of multifunctional biofertilizer (mixture of Bacillus sp. *B. subtillis*, *B erythropolis*, *B. pumilus* and *P. rubiacearum*) plus 50% chemical fertilizer (½ CF + biofertilizer) on a treatment of with chemical fertilizer (CF) and biofertilizer on the growth of lettuce were compared by Young *et al.* (2003). Results showed there was a 25% increase of lettuce yield for the treatment of ½ CF + biofertilizer compared to that of the CF treatment, indicating that at least 50% of chemical fertilizer can be saved as multifunctional biofertilizer was used along with chemical fertilizer (Table 2).

Young *et al.* (2004) evaluated the effects of multifunctional biofertilizer (mixture of Bacillus sp. *B. subtillis*, *B erythropolis*, *B. pumilus* and *P. rubiacearum*) on rhizosphere microbial activity and the growth of water celery in a field experiment. Results showed that the dry weight of water celery in the treatment with 50% organic compound fertilizer with multifunctional biofertilizer (MC + ½ OCF) was increased by 34% compared to the treatment with 100% organic compound fertilizer added (OCF) (Table 3). In addition, the beneficial bacterial counts including mineral PSB, cellulolytic bacteria and N_2-fixing bacteria in the rhizosphere of water celery in the MC + ½(OCF) treatment were increased 102~104 CFU/gin.

Integrated use of chemical, organic and biofertilizers

Increased attention is now being paid to developing an Integrated Plant Nutrition System (IPNS) that maintains or enhances soil productivity through balanced use of all sources of nutrients, including chemical fertilizers, organic fertilizers and biofertilizers. The basic concept underlying the IPNS is the adjustment of soil fertility and plant nutrient supply to an optimum level for sustaining desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner.

We conducted a field experiment to evaluate the effects of chemical fertilization (CF), organic fertilization (Compost-N and Compost-P), combined use of chemical and organic fertilizer (Compost-P + urea) and integrated use of chemic al and organic fertilizer along with biofertilizer (½ (Compost-P + urea) + Biofertilizer) on the growth of cabbage and maize (residual effect) and soil fertility. The amount of fertilizer application in all treatments, except CK, Compost-N and Biofertilizer was based on providing the same amount of P for cabbage, and the release rate of P in compost was assumed to be 30%. In addition, urea was used to supplement deficient N for cabbage in the treatment of Compost-P + urea. Table 4 shows that the Compost-N treatment had the highest relative yield of cabbage and maize due to more nutrient inputs, such as P, K, and other nutrients. The lower relative fresh weight of cabbage in the Compost-P and ½ Compost-P urea treatments compared to the CF treatment was probably due to the shortage of N for cabbage uptake. However, the relative dry weight of maize in all treatments, except CK and biofertilizer, was close to or higher than that of the CF treatment, indicating the residual effect of applied compost. In addition, the combined use of biofertilizer with compost (½ Compost-P + Biofertilizer) and combined use of biofertilizer, compost and chemical fertilizer [½ (Compost-P + urea) + Biofertilizer] had the advantage of saving compost and/or chemical fertilizer. The contents of mineral N (NH_4^+ + NO_3-) and Bray-1 P in all treatments, except CK, were higher than those of the CF treatment, showing the benefits of biofertilizer and compost by supplying and enhancing the release of N and P (Table 5). Excess inputs and excess accumulation of P in soil usually increase their potential to contribute soluble and particulate P to surface waters and result in P-driven eutrophication. The content of Bray-1 P in the test soil was 69 mg/kg, rated as "high" in terms of P availability. There are many suggestions in the literature that significant raising of Bray-1 P content is not good for a soil with a high level of P availability, from the economic and environmental standpoint. The Bray-1 P content of the soil was approximately twice as high in the Compost-N treatment compared to the CF treatment, showing significant P accumulation in the soil. This indicated that reducing half the amount of compost and urea combined with inoculants of mixed strains of beneficial micro-organisms has considerable potential to lessen P accumulation in the soil and saves the input of chemical and organic fertilizers.

Conclusion

Efficient plant nutrition management should ensure both enhanced and sustainable agricultural production and safeguard the environment. Chemical, organic or microbial fertilizer has its advantages and disadvantages in terms of nutrient supply, soil quality and crop growth. Developing a suitable nutrient management system that integrates use of these three kinds of fertilizers may be a challenge to reach the goal of sustainable agriculture; however much research is still needed.

Table 1. The relative yield of cabbage and the contents of Bray-1 P and exchangeable K of the soil after cabbage harvest in different treatments (Tzen and Chen, 2004)

Treatment	Relative yield of cabbage (%)		Bray-1 P	Exchangeable K
	First crop	Second crop	--------- mg/g	----------
CK[†]	0	0	18	25
CF[‡]	100	100	34	31
Compost-N	261	123	131	87
Compost-P	108	75	45	49
Compost-P + Urea	219	212	40	26

[†]No fertilizer applied. [‡]Chemical fertilizer.

Compost-N: The compost application rate was based on the N requirement of cabbage and its N release percentage was assumed to be 50%.

Compost-P: The compost application rate was based on the P requirement of cabbage and its N release percentage was assumed to be 30%.

Compost-P + Urea: The compost application rate was the same as compost-N, but urea was used to supplement deficient N.

Table 2. Effect of biofertilizer and chemical fertilizer on the growth of lettuce (Young *et al.* 2003)

Treatment	Relative fresh weight (%)	Relative dry weight (%)
CK (water)	55	67
½ CF[†]	67	83
½ CF + biofertilizer	111	125
CF	100	100
Biofertilizer	75	110

[†]Chemical fertilizer. Biofertilizer: Combination of *Bacillus* sp. *B. subtillis*, *R. erythropolis B. pumilus* and *P. rabiacearum*

Table 3. Effect of multi-functional organo-biofertilizer on the growth of water celery (28days) (Young *et al*. 2004)

Treatment	Fresh weight		Dry weight	
	g/pot	% of control	g/pot	% of control
CK	58	32	10	57
OCF[†]	165	92	18	100
½ (OCF)	178	100	18	100
MC + ½ (OCF)	222	127	24	134
MC	129	72	13	74

[†] Organic compound fertilizer (N: P_2O_5: K_2O = 17: 7: 7 O.M.:30%).
MC: Multi-functional organo-biofertilizer (mixture of five strains of bacteria with compost).

Table 4. Relative fresh weight of cabbage and maize in different treatments in the field experiment

Treatment	Relative fresh weight (%)	
	Cabbage	Maize
CK	15	86
CF[†]	100	100
Compost-N	105	114
Compost-P	31	104
½ Compost-P + Biofertilizer	28	105
Compost-P + Urea	79	102
½ (Compost-P + Urea) + Biofertilizer	74	99
Biofertilizer	30	92

[†]Chemical fertilizer (Urea, single superphosphate, potassium chloride).

Compost-N: The compost application rate was based on the N requirement of cabbage and its N release percentage was assumed to be 50%.

Compost-P: The application rate of composted animal manure was based on the P requirement of cabbage and the release percentage of P in compost was assumed to be 30%.

Biofertilizer: Mixture of multi-functional bacteria, including *Bacillus pumillu*, *Bacillus subtilis* S. and *Bacillus subtilis.*

Table 5. Some chemical properties of soils in different treatments after harvest of maize

Treatment	O.M. (%)	Mineral N (mg/kg)	Bray-1 P (mg/kg)
CK	1.5	3.9d	69d
CF†	1.4	8.1c	74c
Compost-N	2.1	15b	146a
Compost-P	1.5	18b	88b
½ Compost-P + Biofertilizer	1.5	18b	76c
Compost-P + Urea	1.4	21ab	90b
½ (Compost-P + Urea) + Biofertilizer	1.5	23a	83bc
Biofertilizer	1.2	22ab	71d

†Chemical fertilizer (Urea, single superphosphate, potassium chloride)

Compost-N: The compost application rate was based on the N requirement of cabbage and its N release percentage was assumed to be 50%.

Compost-P: The application rate of composted animal manure was based on the P requirement of cabbage and the release percentage of P in compost was assumed to be 30%.

Biofertilizer: Mixture of multi-functional bacteria, including *Bacillus pumillu*, *Bacillus subtilis* S. and *Bacillus subtilis.*

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