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Sugar Beet Yield Comparison Between Conventional Tillage and Zero Tillage Fields in Hokkaido Japan

Takashi KATAOKA[1], Marlowe Edgar BURCE[2], Hiroshi OKAMOTO[1], Youichi SHIBATA[1], El Kamil TOLA[3]
[1]Crop Production Engineering Laboratory, Research Faculty of Agriculture,
Hokkaido University, JAPAN 060-8589, tkataoka@bpe.agr.hokudai.ac.jp,
hiro@bpe.agr.hokudai.ac.jp, yshiba@bpe.agr.hokudai.ac.jp
[2]Marlowe Edgar BURCE, Crop Production Engineering Laboratory, Graduate School of Agriculture,
Hokkaido University, JAPAN 060-8589, mcburce@bpe.agr.hokudai.ac.jp
[3]El Kamil TOLA, Faculty of Engineering, University of Khartoum, SUDAN, klhtola63@yahoo.com

Abstract: The acreage of zero tillage (ZT) farming in Japan had been statistically negligible over the past decades with local farmers favoring conventional tillage (CT). The objective of this study was to find out if the yield performance of sugar beet crop will vary if cultivated under an inter-mixed field of zero tillage (ZT) and conventional tillage (CT) methods under the soil and weather conditions of Hokkaido, Japan. An experimental field at the Hokkaido University Experimental Farm was divided equally into nine plots. Three tillage treatments at three replications each were randomly distributed among the nine plots to represent one CT field and two replicated residue-free ZT field. A four row air seeder was used to plant the crop for two consecutive cultivation seasons in 2007 and 2008. Yield parameters like root length, root diameter, moisture content, and sugar content were measured from samples from every row of each plot. Statistical analysis on the yield samples from each plot generally showed no significant difference in most yield parameters for the CT field and the ZT field. In this study, the results suggested that under the same crop management conditions, yield output is not affected by the type of tillage system applied. Additional tests are needed to further strengthen the applicability of ZT for sugar beet in the entire Hokkaido region.

Key words: conservation tillage, zero tillage, yield monitoring, sugar beet, weed

INTRODUCTION

One of the basic points that the Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF) stated in the reform of its agricultural policies is the development of measures that takes account of environmental conservation. According to MAFF (2005), emphasis on environmental protection will be applied to all agriculture in Japan.

These reform policies can be supported through zero tillage farming (also known as direct seeding or no-till farming) as one of the promising tillage system for conservation agriculture. This viewpoint is supported by many agricultural organizations (ISTRO, 1997; FAO, 2001) and researchers like Lal (2007) who stressed that, no-till farming, practiced in combination with crop residues, mulch and growing a cover crop in the rotation cycle, is widely recognized by soil scientists and agronomists as a viable alternative to plow tillage for making agriculture a part of the solution to improving the environments and sustaining the use of natural resources. Blanco-Canqui and Lal (2008) described no-tillage farming as an important technology to improving soil processes, controlling soil erosion, and reducing tillage costs, and these are sufficient reasons to promote the conversion of plow tillage to no-tillage farming.

With the benefits of ZT farming aside, the challenge for Japanese agriculture to adopt this system had been met with reservations due to varying climatic conditions around the country. The World Factbook of the Central Intelligence Agency (CIA, 2008) describes Japan's climate as varying from tropical in south to cool temperate in north.

In Hokkaido prefecture, northernmost island of Japan, local farmers are hesitant to apply ZT farming since soil erosion is not a problem but weed management is a major issue because of the favorable soil moisture conditions. The research conducted by Terawaki et al. (2002 and 2004) and Suzuki et al. (2008) confirmed the presence of a variety of weeds in sugar beet fields.

The NARCH (2008) describe Hokkaido as a vast land with favorable agricultural conditions-cool temperature in summer, long daylight hours, ample sunshine and large day-night temperature differences. Hokkaido has an annual mean temperature of 8.5° C with a 26.1° C mean maximum temperature in August of and a -7.7° C mean minimum temperature in January. Annual precipitation is about 1,128 mm. Hokkaido produces 22% of the national food supply (calorie-base), making it a main food base in Japan. The cultivated area of Hokkaido represents 25% of Japan's total cultivated area. Hokkaido is the country's top producer of rice, wheat, beans, potatoes, sugar beets, onions, sweet corn, forage, raw milk and beef. Sugar beet production in 2008 was 4,200,000 tons which is 100% of the national total. Hokkaido's soil is usually made up of volcanic ash, peat soil and heavy clay. The soil is classified to be an Andisol in USA soil taxonomy and as Andosol in FAO soil classification.

Peat soils according to Inisheva (2006) consist of 50–95% organic substances; they are excessively moistened. However, Rahman et al. (2008) mentioned that soil moisture conservation is a critical issue in Andisols of Japan, covering 16.4% of the total land surface, since it has high porosity.

The climate, weeds, and soil conditions of Hokkaido had made it difficult for farmers to adopt this zero tillage system. Many research studies had pointed out the drawbacks in the application of this tillage system. Studies conducted by Rosner et al. (2008) in Austria, where the climate is characterized by an annual average temperature of 8.5 °C – 10.5 °C much more like Hokkaido climate, reported that the yields were significantly lower with minimum tilling in the cultivation of sugar beets due to problems made by the closing of the seed-slots, which led to a reduced number of sugar beet plants. Moreover, the team had problems fighting the arising field bindweed (Convolvulus arvensis) using the active substance Glyphosate. Kocha et al. (2009) also described that in a long-term series of on-farm tillage trials in southern and eastern Germany, sugar beet yield was significantly decreased by direct drilling compared to ploughing. A study conducted in Greece by Cavalaris and Gemtos (2002), reported the conservation tillage yields were reduced in NT fields (26.1-46.6%) compared to CT method. Gemtos et al. (2002) also accounted that conservation tillage research indicated that continuous use of no-tillage or shallow tillage causes an increase in soil dry bulk density, in weed infestation and reduced yields. The research of Costea et al. (2004) on the sugar beet weed—Amaranthus powellii has been reported to reduce yield by about 10% at densities of one plant per 3 m of row, when weeds remained all season and that the weed A. retroflexus, at densities of 1 plant per 2 to 3 m of row, reduced sugar beet yield by 12%, and by 31% at densities of 1.5 plants m–2. Yield reductions from pigweed interference declined 25% as row spacing of sugarbeet decreased from 76 cm to 46 cm.

Furthermore, McCown (n.d.) wrote that the advantage of no-tillage, mulch farming practices over conventional cultivation is much greater in semi-arid tropical region than in temperate or Mediterranean areas. Miyazawa et al. (2002) also cited the work of Cannel and Hawes acknowledging that conservation tillage in the temperate regions therefore has not been very attractive to farmers and its adoption has been limited.

Despite these drawbacks in the application of ZT in other temperate regions in the other parts of the world, studies performed by Miyazawa et al. (2002) in Japan reported better crop performance under conservation tillage in cool, temperate regions as well. The team explored the feasibility of applying conservation tillage for improving crop performance on soybean, sugar beet and spring wheat. Loboski (2002) and Toriyama et al. (2005) also affirmed the benefits of ZT cultivation in temperate regions in terms of crop residue decomposition and organic matter content of the soil. A study on sugar beet cultivation in Japan Andosol fields conducted by Inano et al. (2006) also showed positive results in the emergence rate of the sugar beet plant. Miyazawa et al. (2002) cited that the potential of conservation tillage to promote sustainability of agriculture system irrespective of climatic and soil conditions should be acknowledge (Carter, 1994).

Despite the shown problems it seems in practice possible to use these methods if certain principles are paid attention to such as minimum soil cultivation methods and the use of proven ecological advantages. According to practical data, profit losses are only in the first change-over years, reaching a normal level later, whereby the aforementioned advantages can be used. (Rosner et al., 2008)

Little research and information is available for the economic tradeoffs of weed control devices and chemicals against those of conventional tillage in this area of Japan. Although, the Rice and Wheat Consortium (RWC, 2005) pointed out that zero-till drills can be used in all type of soils except the excessively wet and the compacted soils, actual field tests and research data are insufficiently available to encourage farmers to utilize ZT farming practices. Moreover, Kocha et al. (2009) stated that a high yield is a vital prerequisite for the economical feasibility of conservation tillage and its acceptance by farmers.

In this research, a five-year plan was devised to monitor the yield performance of sugar beet on the experimental field in Hokkaido with inter-mixed ZT and CT plots. The primary objective is to determine if yield results are affected by the type of tillage system used under cool temperate climate conditions.

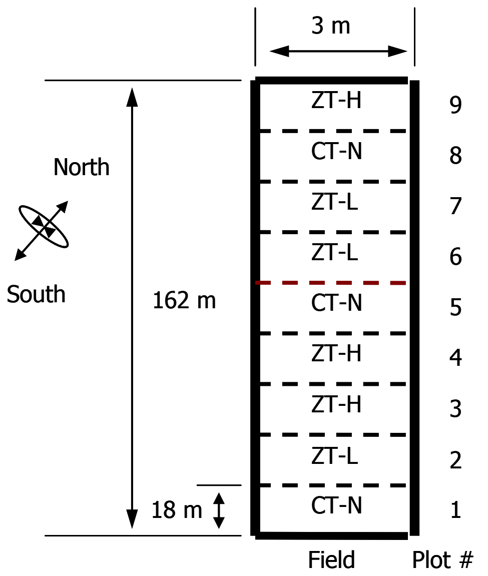
The five-year plan is divided into two stages. The first phase (Phase I), covering the first two years, would involve the cultivation of the said crops with the exclusion of weed and plant residues on the ZT plots. The focus would be on the soil strength characteristics of ZT field and CT field effect on the harvest yield. The next phase (Phase II), covering the remaining three years, would involve the inclusion of actual weed and plant residues during cultivation.

MATERIALS and METHODS

Field preparation

Field experiments were conducted at the Hokkaido University Experimental Farm, Japan at two locations within the farm. The over-all soil texture of the field is 50.5% silt, 28.9% clay, and 19.7% sand. It is categorized to be that of a silt clay loam type based on Japanese standards. The fields were prepared in Spring 2007 (43° 4' 27.21" N, 141° 20' 10.69" E) and Spring 2008 (43° 4' 29.02" N, 141° 20' 10" E). Both locations have field dimensions fixed at 3 meters in width and 162 meters in length.

The fields are all divided into 9 plots (18m × 3m area per plot). Three tillage treatments were applied, namely conventional tillage normal strength (CT-N) zero tillage low strength (ZT-L) and zero tillage hard strength (ZT-H). The tillage treatments had 3 replications each that were distributed randomly among the 9 plots as shown in Fig. 1.



Tillage treatment:
CT-N = conventional tillage normal strength
ZT-L = zero-tillage low strength
ZT-H = zero-tillage high strength

Fig. 1. Experimental field layout showing random distribution of tillage treatments in the 9 plots.

The three CT-N plots where prepared using a rotary tiller to represent CT (Fig. 2). The ZT-L plots and ZT-H plots represent ZT at varying soil strengths. The surface soil of the 3 ZT-L plots, between 0-5 cm from the surface, was compacted using a hand-driven piston roller (Fig. 3). The other 3 ZT-H plots were prepared using two rollers. First, a subsoil roller (Fig. 4) was used to compact the surface soil. This is followed by a hand-driven piston roller to compact the soil below the surface soil just above the top soil layer. The plant residues on both ZT-L and ZT-H plots were removed and cleared before seeding.

Fig. 2 Rotary tiller used in the preparation of the CT-N plots.

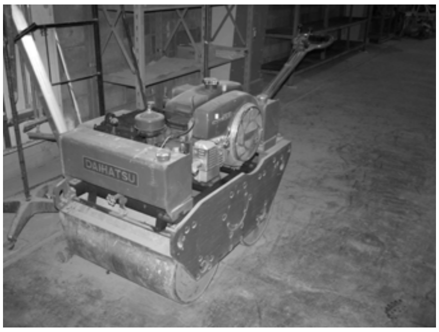


Fig. 3 Piston roller used in the preparation of the ZT-L and ZT-H plots.

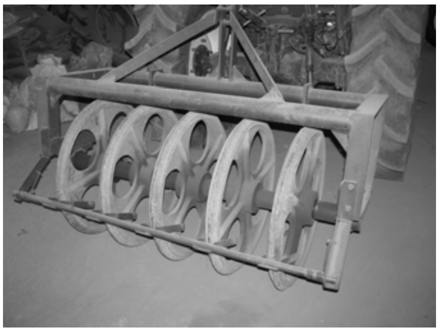


Fig. 4 Subsoil roller used in the preparation of the ZT-H plots.

A cone penetrometer (YAMAZAKI, SR-2) was used to measure the average soil strength cone index (CI) for the two fields with the results shown in Table 1.

Table 1 Soil strength cone index measurement settings for each tillage treatment in 2007 and 2008.

Tillage treatment	Spring 2007	Spring 2008
CT-N	0.382 MPa	0.073 MPa
ZT-L	0.769 MPa	0.662 MPa
ZT-H	0.886 MPa	1.029 MPa

Crop Seeding

Fig. 5 shows the farm tractor (YANMAR, US550) with a conventional tillage 4-row air seeder (TABATA, TJEV-4LR) that was used in seeding of the sugar beet (Beta vulgaris L.).

Fig. 5 Farm tractor with 4-row air seeder used in sugar beet cultivation.

The soybean seeds were first planted during the spring season in May 2007 and in May 2008. In both seasons, the seeding had a target seeding depth of 50 mm at 1 m/s tractor speed. Row spacing varied in Spring 2007 with 660 mm compared to 700 mm in Spring 2008. Seed spacing in Spring 2007 and Spring 2008 was set to 150 mm. Only one seed was planted per seed spacing. The management of the applications in both seasons had the same treatment between the zero tillage field and the conventional tillage field.

Sugar beet yield sampling

The sugar beet were all sampled in the month of October in 2007 and 2008 just before harvest period. Five consecutive plants in each of the 4 rows per plot were randomly collected as samples. The total number of plants sampled per soil hardness configuration is 60 (5 plants × 4 rows × 3 plots) totaling 180 samples.

The shoots of each sample were chopped off and the roots were slowly uprooted preserving the bulb and the roots. Each samples length and widest diameter was measured after uprooting. The samples were then transported to the farm house where it was washed and weighed. The samples are then sliced into cubes of 4 cm × 4 cm × 2 cm with two cubes per sample. The first cube slice was used for moisture content measurement while the second cube slice was used for sugar content measurement. The fresh weight of the first cube slice was measured after slicing and its dry weight was also measured after it was placed in the drying oven for 24 hours at 80° centigrade. The second cube slice was grated manually and the juice was extracted using a tissue paper filter. The extracted sugar beet juice's sugar content was then measured by a refractometer device (ATAGO, PR101α).

The crop yield parameters evaluated in both seasons were root length, widest root diameter, root weight, moisture content, and sugar content. A statistical analysis of variance between each of the 3 tillage treatments for each yield parameter was applied.

Weed Sampling

During the cultivation of the sugar beet, the weeds present in both fields during the two year cultivation season were identified, monitored and then sampled. The identification of the weeds present in both crop fields were conducted by Suzuki et al. (2008).

The monitoring and sampling of the weeds involved counting the weeds per square meter area in the randomly selected CT-N, ZT-L, and ZT-H plots. A 1 m by 1 m light plastic frame was constructed and used in the sampling of the weeds. The plastic frame is thrown in the air randomly over the selected plots. The location where the plastic frame lands is designated as the sampling area. The weeds found inside the 1 m x 1 m light plastic frame is weeded out one at a time and counted manually by hand. Five sampling locations for each of the CT-N, ZT-L and ZT-H plots were collected. A total of 15 sampling locations over the entire field were gathered. The total count for each location is recorded and tabulated. Statistical analysis was applied on the data gathered to test for variations between tillage treatments.

RESEARCH RESULTS

Climate and soil conditions

The climate conditions in Table 2 showed that during the cultivation period from May to the harvest season in November, there had been more sunlight hours and rainfall precipitation in 2007 compared to that in 2008. Daily mean average of both maximum and minimum temperatures suggested that 2008 season is warmer than in 2007. Soil conditions based on soil strength shows that ZT-H plots in 2008 were 14% harder than in 2007 while the other plots are softer with its counterparts in 2007.

Table 2. Climate conditions during crop cultivation in 2007 and 2008.

	Yr.	May	Jun	Jul	Aug	Sep	Oct	Nov
Total precip. (mm)	'07 '08	87.0 65.5	38.0 40.0	45.0 63.5	65.5 56.0	193.5 30.5	66.5 99.5	75.0 86.0
Total sunshine (hrs)	'07 '08	184.0 185.4	223.4 193.8	228.8 146.7	165.7 188.1	125.1 202.9	150.0 161.1	118.5 125.2
Mean daily max. temp. (ºC)	'07 '08	16.8 17.4	23.8 22.0	24.2 25.7	28.3 25.4	23.1 24.2	16.1 16.9	7.7 8.6
Mean daily min. temp. (ºC)	'07 '08	8.9 8.6	15.2 13.2	16.3 18.6	19.6 18.0	15.6 14.9	7.6 9.0	0.2 0.5

Sugar beet yield

Table 3 and 4 shows the mean value results for each tillage treatments for the sugar beet cultivation in 2007 and 2008.

Table 3. Mean values for crop yield parameter results of sugar beet in 2007 for each tillage treatment.

Crop yield parameter	CT-N	ZT-L	ZT-H	*p*-value
Root length (mm)	285.74	286.70	301.78	0.45
Root weight (kg)	2.11	1.77	2.07	0.15
Widest diameter (mm)	138.75	132.19	139.83	0.12
Moisture content (%w.b.)	75.68	75.95	75.65	0.97
Sugar content (%)	19.12	19.15	19.45	0.67

Table 4. Mean values for crop yield parameter results of sugar beet in 2008 for each tillage treatment.

Crop yield parameter	CT-N	ZT-L	ZT-H	*p*-value
Root length (mm)	375.78	365.11	367.78	0.87
Root weight (kg)	2.06	1.97	1.95	0.76
Widest diameter (mm)	131.78	132.36	129.80	0.76
Moisture content (%w.b.)	77.42	78.04	78.07	0.81
Sugar content (%)	17.55	17.30	17.50	0.92

The root length results in 2008 showed higher values compared to the root length results in 2007. The mean values in 2007 indicated that the ZT-H tillage treatment had the longest average root length compared to the other tillage treatment. However, the mean values in 2008 suggested that the CT-N tillage treatment had the longest average root length. This was due to the differences in soil hardness configuration for each cropping season.

Average results between tillage treatments indicated that the CT-N tillage treatment had the heaviest root weight in 2007. The same is also true for the mean results in 2008 where 2.06 kg was registered in the CT-N tillage treatment compared to the zero-tillage treatments. On the average, the widest diameter (139.83 mm) was found in the ZT-H tillage treatment in 2007 and in the ZT-L tillage treatment in 2008. Moisture content was also seen to be higher in the ZT plots for both cultivation seasons. Based on the average values between tillage treatments in 2007, the root crops had more moisture content in the ZT-L tillage treatments compared to the other two tillage treatments. However, low moisture content was observed in the CT-N tillage treatment in 2008. In general, the sugar beet cultivation in 2008 had more moisture content than the ones in 2007 based on the average of the three tillage treatments for each cultivation season. Mean values for sugar content in 2007 was higher compared to the mean values of sugar content in 2008. The over-all average between tillage treatments shows that the CT-N tillage treatment had the lowest sugar content of 19.12%. However, in 2008 the lowest sugar content was found in the ZT-L tillage treatment based on the average values summary. Generally, the sugar content in 2007 was much higher compared to the sugar content in 2008.

The statistical analysis for the comparison between the three tillage treatments on every crop yield parameter in 2007 and 2008 indicated no significant difference with all *p*-values greater than the set significance level of 99.99%. This means that the three tillage treatments applied did not make any significant difference in the root length, root weight, widest diameter, moisture content and sugar content yield parameters of the sugar beet for both cultivation in 2007 and 2008.

Weed Monitoring

Weeds present in both fields for sugar beet were identified during the two cultivation seasons. Suzuki et al. (2008) found the following weeds: mapled leaf goose-foot, field horsetail, pearlwort, houndberry / foxgrape, green amaranth and sobakajura in Japanese. The list is summarized in Table 5 with their equivalent scientific and Japanese names, during the cultivation of the sugar beet crop in 2007 and 2008.

Table 5. Identified weeds found in the cultivation of sugar beet (Suzuki et al., 2008)

English Name	Scientific Name	Japanese Name
Mapled leaf goose-foot	Chenopodium hybridum L.	アカザ
Field horsetail	Equisetum arvense L.	スギナ
Pearlwort	Sagina procumbens	ツメクサ
Hound-berry/fox-grape	Solanum nigrum	イヌホウズキ
Green amaranth	Amaranthus hybridus	アオギイトウ

Fig. 6 shows the visual inspection of the field were the weed sampling was conducted. It can be clearly seen that most weeds were present in the ZT-H plots, a few number in the ZT-L plots, however, only very few weeds are found in the CT-N plots. This is because tillage had been applied in the CT-N plots where most of the initial weeds were destroyed, buried and mixed with the soil after tillage preparation of the plot. The weeds in the zero tillage plots were undisturbed resulting in more weed germination and infestation.

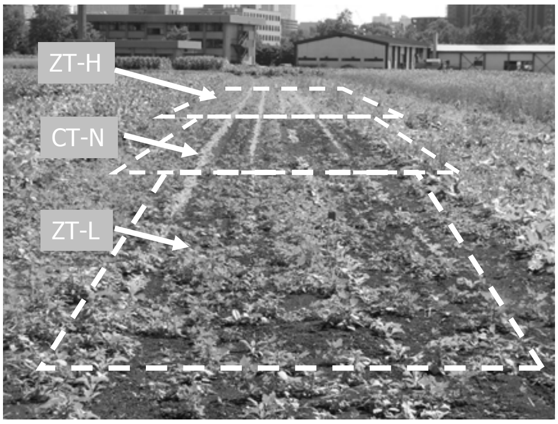


Fig. 6. Visual inspection of sugar beet field with quantity of weeds in some tillage treatment plots.

Further investigation through actual weed count sampling confirmed the assumptions made during visual inspection. The result of the weed count sampling is summarized in Table 6. The weed count in the CT-N plots for all 5 sampling locations registered the lowest count. The lowest number of weeds was found to have only 20 in one of the sample locations. The highest numbers of weeds are found in the ZT-H plots. The highest count for the number of weeds in a given sampling location is 203 weeds. The ZT-L plot weed samples are mostly double in numbers than the CT-N plot weed samples. In two weed sampling locations of the ZT-L plots, the number of weeds exceeded the ones in the ZT-H plots.

Table 6. Summary of weed sampling count

Sampling Location	CT-N	ZT-L	ZT-H
1	37	72	144
2	21	97	120
3	35	89	106
4	33	121	168
5	20	68	203
Sum	146	447	741
Average	29.20	89.40	148.20

Comparing the average number of weeds per tillage treatment, the average number of weed in the zero-tillage treatment area were almost five times more than the CT-N plot weed samples while the average number of weeds in the ZT-L plots are almost thrice the size of the CT-N plot weed samples.

The variation on the density of the weeds between tillage treatments is further confirmed with the statistical results applied on the data. ANOVA results in Table 7 showed that there is significant difference in the number of weeds between CT-N and ZT-L tillage treatments. Significant difference in the number of weeds was also found between CT-N and ZT-H tillage treatments. The *p*-values for both comparisons are lesser than 0.001. However, no significant difference ($p > 0.001$) was found in the number of weeds between ZT-L and ZT-H tillage treatments.

Table 7. Statistical results of weed count

Interaction between treatments	*p*-values
CT-N × ZT-L	0.000359334
CT-N × ZT-H	0.000147778
ZT-L × ZT-H	0.147699833

In summary, there was significant difference in the emergence of weeds between the conventional tillage treatments against the zero tillage treatments. However, there was no significant difference in the emergence of weeds between the two types of zero tillage treatments.

CONCLUSION

The Phase I of this study concludes that the initial absence of plant residues and the varying soil strengths in the zero tillage treatments did not significantly affect the yield performance of sugar beet when compared to that of the conventional tillage treatments.

Thus, residue-free zero tillage can possibly be accepted as an alternative to conventional tillage application for sugar beet cultivation in this study. This will reduce fuel cost and save labor time for the farmer. However, the application of zero tillage all over Japan would require lesser application of herbicides and chemicals for weed control in order for consumers and public markets to accept it as safe for food production.

Further study is needed to evaluate the effects of plant residues on yield for both zero tillage and conventional systems. More field tests should be conducted in the Hokkaido region before substantial results can be concluded.

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