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Conservation agriculture responses to yield and water productivity in direct seeded rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted on rice at Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi, to evaluate the effect of conservation agriculture on yield, water productivity and biophysical parameters of direct seeded rice and soil properties. Results revealed that TPR – CTM plots had significantly higher rice grain yield (51.9 q ha^{-1}) than all plots with conservation agriculture practices. However, the mungbean residue+ zero-tillage rice-rice residue + zero tillage mustard + mustard residue-summer mungbean (MBR+ ZT DSR – RR + ZTM + MR – SMB) treatment had significantly higher grain yield from other DSR plots which was at par with transplanted rice-zero tillage mustard (TPR – ZTM), and MBR + ZT DSR – ZTM – SMB treatments. Similar results were also found for straw yield and harvest index. Further though gross and net returns were higher in TPR plots, but B:C ration was highest in the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment. The total irrigation water applied to MBR+ ZT DSR – RR + ZTM + MR – SMB treatment was less compared to all other treatments and also highest water productivity (3.27 kg ha^{-1}mm^{-1}) than all other DSR and TPR plots. Results revealed that rice under the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment produced taller, plants, height, higher leaf area, leaf area index, relative water content, and chlorophyll concentration of the plants. There was slightly increase in organic carbon and available N, P, K in DSR plots compared to transplanted plots at 0-15 cm depth. Therefore, direct seeded rice under triple zero tillage of conservation agriculture grown with mustard in rabi season and moonbean in summer season can be the best option for alternate to puddled transplanted rice in Indo-Gangetic plain (IGP) of India.

Keywords: Rice, transplanted, DSR, conservation, agriculture, productivity

INTRODUCTION

Rice crop consumes large quantity of irrigation water, ranging between 1500 and 3000 mm (Sharma *et al.*, 2002). Agricultural Policy Vision 2020 of Indian Council of Agricultural Research, India has projected 112 million tonnes of rice requirement in 2020, which is 23 million tonnes more than the present rice production (Mahajan *et al.*, 2012). Water, energy and labour scarcity, decrease in groundwater table, enhancing cost of production, diminishing farm profits and uncertain weather events are major challenges faced by the farmers under intensive tillage based conventional rice cultivation in the north-western (NW) India and Indo-Gangetic Plains (IGP) (Jat *et al.,* 2012 and Mahajan *et al.*, 2012). Therefore, the sustainability of rice production and the overall environment in these areas are most threatened. Conservation agriculture which is a burning issue now-a-days for enhancing crop yields, economic and environmental benefits may be best practice to address these threats. It is being developed, adapted and promoted in Indo-Gangetic Plains (IGP) in South Asia (Jat *et al.*, 2014; Sapkota *et al.*, 2014). The conservation agriculture principles such as minimum soil disturbance, permanent soil cover, and appropriate crop rotation with zero-till technology makes successful and contribute added advantage to the farmers (Jat *et al.*, 2011; Das *et al.*, 2014; Bhattacharyya *et al.*, 2015; Freitas and Landers, 2014).

Puddling, followed by hand-transplanting of rice seedlings and consecutive flooding, is the traditional method of rice culture in the Indo-Gangetic Plains (IGP) of South Asia which consumes a lot of energy (for intensive tillage), labour and water (Yadav *et al.*, 2011; Dass *et al.,* 2016). Further, it also degrades the physical properties of soil, adversely affects the performance of succeeding upland crops, and contributes to methane emissions. Therefore, this traditional transplanted rice cultivation method, drive the search for alternative management technique to enhance water productivity in rice cultivation (Farooq *et al.*,

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2011). Direct seeding of rice (DSR) in irrigated rice ecosystems (Kumar and Ladha, 2011) can be a best option which could lead to have potential water savings at the field level because of declined evaporation losses (Humphreys *et al.*, 2010; Joshi *et al.*, 2013; Farooq *et al.*, 2011;). It contains sowing pre-germinated seeds into a puddled soil surface (wet seeding), standing water (water seeding) or dry seeding into a prepared seedbed (dry seeding). A study w.r.t. the response of mungbean residue from flooding at different growth stages on growth and yield of DSR showed enhancement of rice grain yield in rice mungbean mixed cropping. Thus, utilization of mungbean residue under water level control situations is a feasible alternative for farmers (Suriyakup *et al.*, 2007). Another study on the effect of *Sesbania* green-manuring (GM), and mustard-residue recycling on soil health and productivity of Indian mustard under fallow–mustard sequence showed that *Sesbania* GM significantly enhanced soil organic carbon (SOC), carbon-sequestration-potential rate, infiltration rate, available NPK status and reduced bulk density. This enhancement in soil properties due to *Sesbania* GM and mustard-residue recycling significantly affected growth, yield attributes and ultimately seed-and oil-yield compared to the existing fallow–mustard practice (Premi *et al.*, 2013). There is lots of literature available on the tillage and water requirements of crops of rice and wheat, but insufficient information is available on the tillage and water requirement of rice, mustard and mungbean crop, whenever grown, in a system mode (Sharma and De Datta, 1986). Therefore, this study was conducted to know the effect of direct seeded rice under conservation agriculture on water productivity, soil properties and other biophysical parameters of rice when grown in a system mode.

MATERIALS AND METHODS

The experiment was conducted on rice hybrid cv. ‘PRH 10’ during kharif season of 2015 at Research Farm of the Indian Agricultural Research Institute, New Delhi. The region has a sub-tropical and semi-arid climate with hot and dry summers and cold winters. May and June are the hottest months. The mean annual rainfall is 710 mm, of which 80% received during southwest monsoon from July to September and the rest from December to February. The mean wind velocity varies from 3.5 km h^{-1} during October to 4.3 km h^{-1} in April. Pan evaporation varies between 3.5 to 13.5 mm d^{-1} (Bhattacharya *et al.,* 2015). The experiment was laid out in a randomized complete block design with eight treatments viz. ZT DSR – ZTM: zero till direct seeded rice (ZT DSR) – zero till mustard, ZT DSR + BM – ZTM: DSR + Sesbania brown manuring – ZTM, MR (mustard residue) + ZT DSR – RR (rice residue + ZTM, MR + ZT DSR + BM – RR + ZTM, MBR (mungbean residue) + ZT DSR – ZTM – SMB (summer mungbean), MBR+ ZT DSR – RR + ZTM + MR – SMB, TPR (transplanted rice) – ZTM, and TPR – CTM (conventional till mustard) and three replications under irrigated conditions, where already mustard and moongbean grown during rabi season of 2014-15 and summer season of 2015, respectively. The soil of the experimental field is under clay loam, sandy clay loam and sandy loam in texture and having pH 8.43, 8.45 and 8.42, EC 0.38, 0.32 and 0.30 dSm^{-1}, bulk density 1.55, 1.67 and 1.72 g cm^{-3}, field capacity 19.7, 14.7 and 12.8% and permanent wilting point 8.1, 5.8 and 4.2% (weight basis) at 0-15, 15-30 and 30-45 cm depth, respectively. The treatments where rice residues were retained and zero tillage was practiced with a cover crop were considered as CA practices. Brown manuring was done by using seeding of rice and sesbania crops together and suppressing of sesbania crop after 25 days.

Soil samples were collected from 0-15, 15-30 and 30-45 cm soil depth before and after experimentation for analysing organic carbon (Walkley and Black, 1934), available nitrogen (Subbiah and Asija, 1956), available phosphorus (Olsen *et al.*, 1954), available potassium (Hanway and Heidal, 1952) and periodically for soil moisture before irrigation to know the status of the present soil moisture content at the crop root zone and deciding when and how much to irrigate. The amount of water to be applied was determined using on the soil moisture depletion method (Bhattacharyya *et al.*, 2015). The amount of water applied for irrigation, nursery raising, pre sowing irrigation, puddling and ponding (in TPR) were measured by using the instrument starflow meter. Effective rainfall was estimated by using FAO method (Allen *et al.*, 2006). Total water applied was estimated as the sum of irrigation water applied and effective rainfall. Water productivity was estimated by taking the ration of grain yield to the total water use during the crop period.

The chlorophyll in plant leaf was determined by hand-held chlorophyll SPAD meter (model SPAD-502, Minolta Corp., Ramsey, N.J.). The area of fresh green leaves for was measured by using leaf area meter (Model LICOR 3000, USA) and was expressed in cm^2 $plant^{-1}$ and leaf area index (LAI) was calculated using the formula suggested by Watson (1957) as the ratio of total leaf area (cm^2)/plant) to ground area (cm^2)/plant. Leaf samples collected for leaf area measurement were chopped to smaller leaflet discs through cutter. Fresh weight of samples recorded quickly and placed in water to make it turgid. After hydration for 6 hours, turgid weight was taken and kept for oven drying at 60^0C for 48 hours. Relative leaf water content (RLWC) was estimated by taking the ratio of (Fresh weight-dry weight) to (Turgid weight-dry weight) and multiplied by 100 (Reddy, 2012). Total biomass, grain and straw yields were recorded at harvest. Harvest index was calculated by the formula using the ratio of economic yield (kg) to biological yield (kg). Economics of cultivation of rice was computed on the basis of prevalent market prices of inputs and output. Statistical analyses for bio-physical parameters were done using analysis of variance (ANOVA) for a complete randomized block design. Tukey's honestly significant difference test was used as a post hoc mean separation test ($P < 0.05$) using SAS 9.3 (SAS Institute, Cary, North Carolina, USA). The LSD's procedure was used where the ANOVA was significant under different rice establishment.

RESULTS AND DISCUSSIONS

Growth attributes

The plant height recorded at 65 days after transplanting (DAT) or 90 days after sowing height was influenced by conservation agriculture practices (Table 1).

Table 1: Growth and biophysical parameters in direct seeded rice at maturity stage

Treatment	Plant height (cm)	No. of tillers/ plant	Dry matter accumul-ation (g)	Leaf area (cm^2)	Leaf area index	Relative leaf water content (%)	Chlorophyll concentration (SPAD value)
ZT DSR - ZTM	76.6	9	26.0	365.3	2.22	0.37	35.11
ZT DSR + BM - ZTM	75.5	9	23.0	211.0	2.11	0.36	34.60
MR + ZT DSR – RR + ZTM	77.2	9	25.0	369.5	2.26	0.38	35.40
MR + ZT DSR + BM – RR + ZTM	79.0	9	24.0	243.0	2.28	0.39	36.80
MBR + ZT DSR – ZTM - SMB	84.4	9	28.8	365.8	2.28	0.42	36.70
MBR+ZT DSR–RR+ZTM+MR-SMB	100.9	11	34.3	384.6	3.99	0.53	38.87
TPR - ZTM	100.6	11	35.2	389.1	3.89	0.51	42.60
TPR - CTM	101.9	12	36.4	395.0	3.99	0.52	44.82
LSD (P = 0.05)	3.13	1.92	0.32	4.54	0.05	0.03	0.70

The treatment TPR – CTM recorded taller plants (101.9 cm) which was statistically at par with the conventional MBR+ ZT DSR – RR + ZTM + MR – SMB and TPR – ZTM treatments and the remaining treatments showed almost similar plant height. The ZT DSR + BM – ZTM treatment showed minimum plant height (75.5cm). The higher plant heights in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment could be due to the more amount of the residue which leads to conserve more moisture for plant growth compared to other conservation treatments and it has quite similar height compare to the conventional treatments despite of being continuously flooding. The number of effective tillers /plant in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment was significantly higher than all other DSR plots and it was at par with TPR treatments. Data (Table 2) indicated that the leaf area ranged between 211 and 398.7 cm^2 in DSR with conservation agriculture plots, whereas 389.1 to 398.6 cm^2, in TPR plots. The results indicated that leaf area was significantly higher in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment compared to MBR + ZT DSR – ZTM – SMB, MR + ZT DSR + BM – RR + ZTM, MR + ZT DSR – RR + ZTM, MR + ZT DSR – RR + ZTM, ZT DSR + BM – ZTM, ZT DSR – ZTM and TPR – CTM treatments 90 DAS (65 DAT). Similarly MBR+ ZT DSR – RR + ZTM + MR – SMB treatment had significantly higher leaf area index (3.99) compared to all other treatments except TPR – CTM (Table 2). Similar observations were made in dry matter accumulation (Table 1) i.e. MBR+ ZT DSR – RR + ZTM + MR – SMB treatment was significantly different and higher (40.1 to 182.1 %) than all other DSR treatments as well as in TPR treatments.

The results on Relative Leaf Water Content (RLWC) revealed that MBR+ ZT DSR – RR + ZTM + MR – SMB treatment had significantly higher value (0.53) compared to MBR + ZT DSR – ZTM – SMB, MR + ZT DSR + BM – RR + ZTM, MR + ZT DSR – RR + ZTM, MR + ZT DSR – RR + ZTM, ZT DSR + BM – ZTM treatments . Conservation agriculture direct seeded rice MBR+ ZT DSR – RR + ZTM + MR – SMB treatment had a very good performance with respect to relative leaf water content might be due to conserving more moisture. Similarly chlorophyll concentration of the plants (SPAD) for different treatments at maturity ranged between 34.6 and 38.87 in DSR with conservation agriculture plots, whereas 42.6 to 44.82 in TPR plots (Table 2). The treatment MBR+ ZT DSR – RR + ZTM + MR – SMB treatment was significantly higher in chlorophyll content in plants compared to others.

Table 2: Water productivity and yield of rice as affected by conservation agriculture practices

Treatment	Irrigation water applied (mm)	Effective Rainfall (mm)	Total water applied (mm)	Grain yield (qha^{-1})	Straw yield (qha^{-1})	Biological yield ($q ha^{-1}$)	Harvest Index (%)	Water productivity ($kg ha^{-1} mm^{-1}$)
ZT DSR - ZTM	926	495	1421	37.6	55.5	93.1	40.3	2.64
ZT DSR + BM - ZTM	941	495	1436	20.0	42.5	62.5	32	1.39
MR + ZT DSR – RR + ZTM	954	495	1449	31.0	50.5	81.5	38.3	2.14
MR + ZT DSR + BM – RR + ZTM	918	495	1413	24.1	48.8	73.0	33.1	1.71
MBR + ZT DSR – ZTM - SMB	913	495	1408	42.6	60.0	100.6	41.1	3
MBR+ZT DSR-RR+ZTM+MR-SMB	893	495	1388	45.7	65.1	110.8	41.3	3.29
TPR - ZTM	1418	491	2003	49.9	80.5	130.4	38.3	2.49
TPR - CTM	1465	491	2054	51.9	78.3	130.2	40	2.53
LSD (P = 0.05)				2.8	0.8	1.2	2.0	0.21

Yield and water productivity

It was found from data (Table 2) that TPR – CTM plots had significantly higher rice grain yield (51.9 q ha^{-1}) as compared to all plots with conservation agriculture practices and 6.2 q ha^{-1} more than the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment. However, the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment had significantly higher grain yield from other DSR plots, while the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment had 8.3 % high grain yield than MBR + ZT DSR – ZTM – SMB treatment. Significant difference was observed among ZT DSR – ZTM and MR + ZT DSR – RR + ZTM treatments, the lowest grain yield (20.0 q ha^{-1}) was obtained with ZT DSR + BM – ZTM treatment. Similarly, TPR – ZTM plot had significantly higher rice straw yield than DSR treatments. Straw yield ranged from 42.5 q ha^{-1} in ZT DSR + BM – ZTM to 65.0 q ha^{-1} in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment of DSR. The MBR + ZT DSR – ZTM – SMB and MBR + ZT DSR – ZTM – RR + SMB treatments were at par with each other in straw, biological yields and harvest index. Further the ZT DSR – ZTM, and MR + ZT DSR + BM – RR + ZTM treatments were significantly different between each other in grain, biological yields and harvest index. The MBR+ ZT DSR – RR + ZTM + MR – SMB treatment recorded significant higher harvest index as compared to MR + ZT DSR + BM – RR + ZTM, ZT DSR + BM – ZTM and TPR – ZTM treatments and at par with MBR + ZT DSR – ZTM – SMB, ZT DSR – ZTM and TPR – CTM treatments.

Water productivity was significantly higher in the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment (3.29 kg $ha^{-1}mm^{-1}$) than all other DSR and TPR treatments due to large reduction in application of irrigation amount during the growing season, followed by MBR +

ZT DSR – ZTM – SMB treatment (2.53 kg $ha^{-1} mm^{-1}$) while water productivity of the two TPR treatments was almost similar (Table 2). The lowest water productivity was observed in ZT DSR + BM – ZTM, and MR + ZT DSR + BM – RR + ZTM treatments despite of being applied more irrigation water compare to MBR + ZT DSR – ZTM - SMB treatment and this reduction in water productivity is due to low grain yield (Table 2).

In general, the highest values of most of the growth and other biophysical parameters were recorded from the MBR+ ZT DSR – RR + ZTM + MR – SMB studied. The brown manuring and mustard residue treatments (ZT DSR + BM – ZTM, and MR + ZT DSR + BM – RR + ZTM) did not performed well as mustard contains allylinothiocyanate which has some allelopathic impact on rice and also due to the nematode infestation which results in poor growth in the whole plant. The grain, straw and biological yields and harvest index of rice were also influenced significantly by conservation agriculture practices. However, highest grain yield was obtained from the transplanted TPR – CTM treatment (5.19 t ha^{-1}), which was 0.62 t ha^{-1} more than the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment. Bazaya *et al.* (2009) reported that overall, conventional sowing produced 20.9% more grain yield than zero tillage. Birhane (2013) studied the difference between the yields achieved from direct sowing and transplanting could be because of less completion for growth resources in transplanting and better air circulation which reduced the prevalence of insect pest and diseases infestation. This yield differences in the method of planting could be due to better establishment or growth of rice plants as a result of lesser competition for water, sunlight and nutrients.

Table 3: Effect of different treatments on economics of rice under conservation agriculture

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B : C
ZT DSR - ZTM	46500	83261	36761	0.79
ZT DSR + BM - ZTM	48300	46402	-1898	-0.04
MR + ZT DSR – RR + ZTM	61800	69385	7585	0.12
MR + ZT DSR + BM – RR + ZTM	66300	55603	-10697	-0.16
MBR + ZT DSR – ZTM - SMB	55830	93371	37541	0.67
MBR+ ZT DSR – RR + ZTM + MR - SMB	56640	101173	44533	0.79
TPR - ZTM	65931	111833	45902	0.7
TPR – CTM	65931	115523	49592	0.75

Benefit: cost (B: C) ratio

The results on gross return, net return, and benefit cost (B: C) ratio showed that the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment had higher gross return, and net return than MBR + ZT DSR – ZTM – SMB, MR + ZT DSR + BM – RR + ZTM, MR + ZT DSR – RR + ZTM, MR + ZT DSR – RR + ZTM, ZT DSR + BM – ZTM treatments (Table 3). On the other hand the MBR+ ZT DSR – RR + ZTM + MR – SMB treatment was at par with ZT DSR – ZTM treatment in benefit cost ratio. However, highest gross return (`. 115523 $ha^{-1}$), and net return (`. 49592 ha^{-1}) were obtained in TPR – CTM treatment (Table 5). The lowest gross return (`. 46402 $ha^{-1}$) was obtained in ZT DSR + BM – ZTM treatment and the lowest net return (`.-10697 ha^{-1}), and benefit cost ratio (-0.16) were found in MR + ZT DSR + BM – RR + ZTM treatment.

Soil fertility

The maximum infiltration rate was obtained in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment amounting 0.94 cm hr^{-1} compared to all other DSR as well as TPR treatments. The infiltration rate in direct seeded rice (DSR) and TPR plots varied from 0.38 to 0.94 cm hr^{-1} and 0.36 to 0.37 cm hr^{-1}, respectively. The organic carbon before and after experimentation at 0 - 15 cm soil depth was 0.55 and 0.61 % which is 10.9 % more in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment respectively, followed by MBR + ZT DSR – ZTM – SMB and MR + ZT DSR + BM – RR + ZTM treatments which was 0.51, 0.55 and 0.47, 0.50

Table 4: Fertility status of before experimentation and post harvest soil under different treatments

Treatment	Available nutrient ($kgha^{-1}$)											
	Org. C %	N	P	K	Org. C %	N	P	K	Org. C %	N	P	K
	Before Experimentation											
	0 - 15 cm				15 - 30 cm				30 - 45 cm			
ZT DSR - ZTM	0.46	143.2	27.5	326.6	0.26	96.3	16.9	224.5	0.18	62.5	11.8	156.9
ZT DSR + BM - ZTM	0.47	143.2	25.3	359.9	0.28	78.1	17.5	225.2	0.19	57.3	12.5	157.4
MR + ZT DSR – RR + ZTM	0.48	143.2	24.6	373.6	0.27	72.9	17.6	226.4	0.19	57.3	13.7	157.6
MR + ZT DSR + BM – RR + ZTM	0.47	124.3	26	375.9	0.29	75.5	18.4	225.9	0.2	57.3	13.6	156.7
MBR + ZT DSR – ZTM - SMB	0.51	143.2	30	336.9	0.26	59.9	19.6	224.9	0.2	52.1	12.3	156.5
MBR+ ZT DSR – RR + ZTM + MR - SMB	0.55	143.2	35.7	377.3	0.33	85.9	20.6	235.9	0.21	52.1	14.5	163.6
TPR - ZTM	0.47	143.9	29.2	313.5	0.29	80.7	19.5	202.8	0.17	44.3	13.4	107.6
TPR - CTM	0.46	153.6	28.3	348.9	0.28	93.7	16.7	204.9	0.16	59.9	12.2	106.7
	After Experimentation											
ZT DSR - ZTM	0.47	145.2	20.4	306.6	0.16	70.3	10.9	204.4	0.11	28.6	9.8	135
ZT DSR + BM - ZTM	0.49	124.9	20.5	347.5	0.19	54.7	13.5	201.3	0.13	33.8	9.5	132.5
MR + ZT DSR – RR + ZTM	0.47	122.3	19.9	345.4	0.16	41.7	14.6	202.4	0.11	28.6	10.7	144.5
MR + ZT DSR + BM – RR + ZTM	0.5	127.6	21.5	348	0.19	49.5	15.6	202.8	0.1	23.4	10.6	145.2
MBR + ZT DSR – ZTM - SMB	0.55	150.0	26.9	300.9	0.22	57.3	16.4	200.9	0.13	33.8	9.3	142.4
MBR+ ZT DSR – RR + ZTM + MR - SMB	0.61	152.4	30.5	353	0.27	59.9	17.5	225	0.10	26.0	11.5	156.8
TPR - ZTM	0.46	146.4	25.7	297.7	0.1	26	14.2	194.6	0.08	20.8	10.4	95.6
TPR - CTM	0.46	145.2	25	329.9	0.11	67.7	13	185.3	0.08	46.9	8.2	96.2

%, which is only 7.84 and 6.38 % more, respectively (Table 4). Further, the maximum enhancement of nitrogen was observed in MBR+ ZT DSR – RR + ZTM + MR – SMB treatment which was 6.43 % more in 0-15 cm soil depth. There was considerable increase in available nitrogen (N) in direct seeded rice (DSR) treatments at 0-15 cm soil depth which ranging from 1.4 to 6.43 %, whereas in the TPR – ZTM treatment there was only 1.69 % enhancement in avialable nitrogen. In contrarily, there was no variation in organic carbon as well as in available N, P, and K in 15-30 and 30-45 cm soil depth in all DSR as well as TPR treatments.

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