INFLUENCE OF DRAINAGE AND FERTILIZATION ON NITROGEN LEACHING

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Introduction

Out of the total nitrogen added into soil with mineral fertilizers, plants get about 50 %, about 25 % is immobilized in soil, and about 25 % is lost through leaching, denitrification and other mechanisms (*Azem et al.,* 1985). From the ecological viewpoint, nitrogen has special importance because of its possible pollution of surface and ground waters. As nitrogen is predominantly leached in the form of nitrates since the soil does not adsorb ions, the hazard of environmental pollutions is generally to the nitrate form of nitrogen, and less to its ammonium and nitrite forms. Groundwater pollution by nitrates is an international problem (***Roberts and** Marsh*, 1987; ***Meybeck et al.***, 1989; ***Weisenburger,*** 1991; ***Spalding and Exner,*** 1993; ***Zhang et al.,*** 1996; ***Lerner et al.,*** 1999; ***Wakida and Lerner,*** 2002).

Excessive nitrate concentration in water may lead to eutrophication of watercourses or stock watering places. If such water is used for human consumption, it may cause methemoglobinemia in infants and animals (***Pratt and Jury,*** 1984. Potential cancer risk from nitrate-N (and nitrite) in water and food has been reported (***Rademaher et al.,*** 1992; and ***Jasa et al.***, 1999). Therefore is the World Health Organization recommended that drinking water should contain less than 10 mg NO_3-N L^{-1} or 50 mg NO_3 L^{-1} (*WHO*, 1998). Leaching of nitrates from soil depends on a number of factors such as, the amount, frequency and intensity of precipitation, soil properties, crop type and crop development stage, evaporation, soil tillage practices, and nitrogen fertilization (*Gausey*, 1991; ***Vidacek et al.,*** 1996, 1999; ***Josipovic et al.,*** 2006; ***Nádasy and Nádasy,*** 2006; ***Németh,*** 2006; ***Nemcic et al.,*** 2007; ***Mesic et al.,*** 2007 and 2008; ***Simunic et al.,*** 2002, 2011).

The problem of nitrate leaching is even more pronounced in agro-ecosystems of hydro-ameliorated fields, especially in drained soils because of changed infiltration and filtration capabilities of these soils. Different drainpipe spacing and different nitrogen fertilization levels significantly influence soil productivity in the experimental area, but may lead to contamination of drainage water with nitrogen pollutants (***Milburn and Richards,*** 1994; ***Klacic et al.,*** 1998; ***Webster et al.,*** 1999).

Keywords: drainage, nitrate, precipitation, leaching, Gleyic Podzoluvisol

Drainage and fertilization

In Croatia the total hydroameliorated areas cover 600,054 ha, including 117,865 ha of the pipe drainage system area (Vidacek et al., 2006). From the total hydroameliorated areas the largest area is located in the Sava river valley, which characterized different types of hydromorphic soils and clayey texture content. From all hydromorphic soils the more extended is Gleyic Podzoluvisol (*Photo 1,* which the major physical and chemical properties are given in ***Table 1***). Drained Gleyic Podzoluvisol is located on level relief (slope<1%o), at an average altitude of 100 m a.s.l. Before the hydroamelioration was set up, the area (soil) was utilised as a pasture, which was in association with swamp vegetation (***Salix sp., Juncus sp. etc)***.

Photo 1 Profile of Gleyic Podzoluvisol (From *Simunic*)

The soil has silty clayey texture to the depth of 0.75 m. The clay content of this soil section is in the range of 46-48 %, and the silt content is 45-47 %. The soil depth of 0.75-1.15 m is of lighter texture. The silt component preponderates in soil texture (55 %), while the clay content decreases (39 %). The soil is porous with the total pore volume of 48-49 %. Soil water capacity is 42-45 %. Air capacity is low (4 %). Vertical hidraulic conductivity is very low (0.001 m/day). Humus content is good (3.03 %), while contents of P_2O_5 and K_2O are very low.

Table 1 Major properties of drained Gleyic Podzoluvisol

Profile	Depth (cm)	Content of particles (%)		Porosity (%)	Capacity (%)		Permeability (m/day)	pH KCl	Humus (%)	P_2O_5	K_2O
		Silt	Clay		Water	Air				mg/100 g soil	
Ap	0-35	47	46	48	44	4	0.011	5.3	3.03	1.51	8.3
Bt,g	35-75	45	48	49	45	4	0.011	5.2			
Gso	75-115	55	39	46	42	4	0.011	7.1			
Gr/c	115-130	45	49	49	46	3	0.011	5.9			

On hydroameliorated soils on a few locations in the Sava river valley are established experimental amelioration fields. Experimental amelioration field is located on soil type defined as Gleyic Podzoluvisol, which involved four different drainpipe spacing (15 m, 20 m, 25 m and 30 m), set up in four replications. All drainpipes spacing were combined with gravel as contact material in the drainage ditch above the pipe. Drainpipe characteristics were: length 95 m, diameter 65 mm, average slope 3 % and average depth 1 m. Drainpipes discharged directly into open canals and drainage discharge was measured continually by means of automatic electronic gauges (limnimeters), which were set up at the drainpipe outlet into the open canal (*Figure 1*). Typical crops for these agro-ecologically conditions were grown, but frequently in rotation as the trial crops were grown maize and winter wheat *Photo 2*). Maize was grown in five trial years (1991, 1993, 1996, 1999 and 2002) and winter wheat in two trial years (2006/07 and 2008/09). Sowing of maize was done in May and harvest took place in October. All measurements were taken from May to April of the following year because soybean was planted as the next crop in rotation in May. Total nitrogen fertilization was: 175

kg ha^{-1} in 1991, 145 kg ha^{-1} in 1993, 145 kg ha^{-1} in 1996, 155 kg ha^{-1} in 1999 and 164 kg ha^{-1} in 2002. Winter wheat was sown in October and harvested in July. Total nitrogen fertilization was: 179 kg ha^{-1} in 2006-07 and 184 kg ha^{-1} in 2008-09. At maize and winter wheat in all investigation year total nitrogen was added with basic fertilization and topdressing.

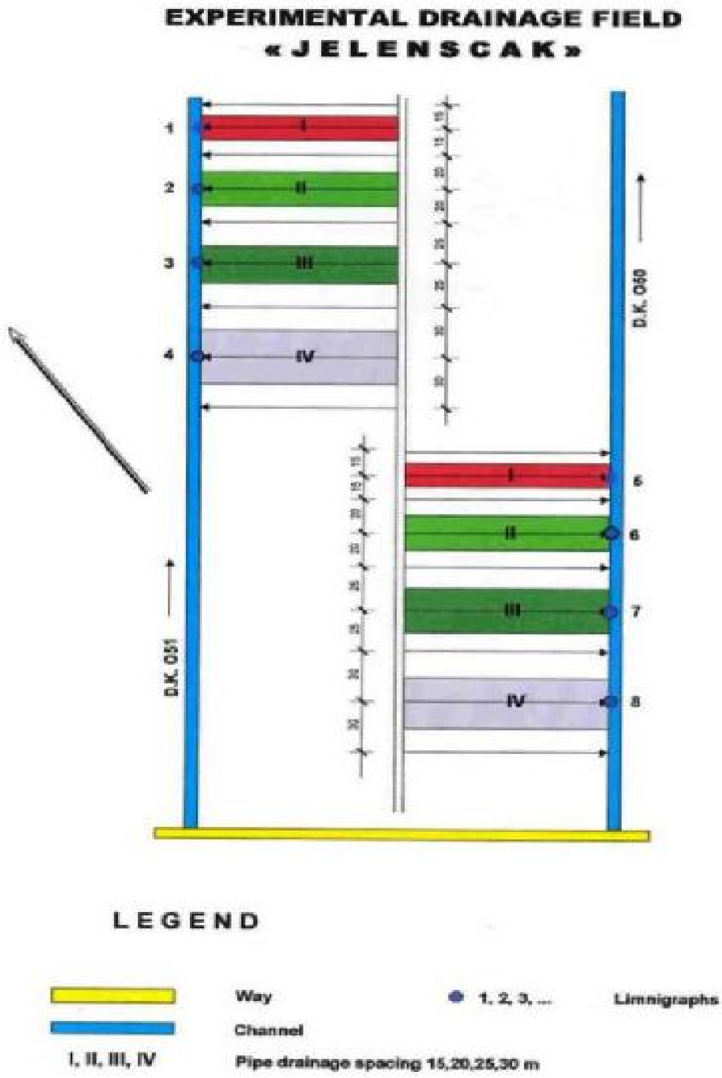

Figure 1
Experimental drainage field

Photo 2 Crops in trial (From *Simunic and Filipovic*)

Hydrological relations

Monthly precipitation values and the corresponding total values (i.e., sum of monthly precipitation values for the whole examined period) are presented in *Table 2.*

Table 2 Monthly precipitation values and the corresponding total values (mm) (From Meteorological Station, Sisak)

Year	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**I**	**II**	**III**	**IV**	**Σ**
1991/92	156	20	160	52	50	152	108	21	15	45	78	59	916
1993/94	44	134	30	119	90	107	165	112	50	58	37	79	1025
1996/97	71	31	90	83	190	46	135	79	44	55	26	45	895
1999/00	107	89	86	66	95	72	92	104	29	37	63	77	917
2002/03	183	56	130	99	133	73	113	54	71	21	5	30	968
Year	**X**	**XI**	**XII**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Σ**
2006/07	27	86	28	82	58	85	7	92	43	27	55	141	731
2008/09	88	86	101	113	40	54	31	44	153	171	37	30	948

Table 3 Quantities of drainage discharge (mm) and total duration of drainage discharge (days)

Drainpipe spacing (m)	**Year**	Precipitation (mm)	Drainage discharge		Duration of drainage discharge (days)
			mm	% of precipitation	
15			228	24.9	134
20	**1991/92**	916	219	23.9	136
25			213	23.3	139
30			229	25.0	141
15			266	26.0	167
20	**1993/94**	1025	271	26.4	170
25			268	26.1	177
30			277	27.0	182
15			198	22.1	140
20	**1996/97**	895	198	22.1	146
25			203	22.7	153
30			199	22.2	157
15			174	19.0	124
20	**1999/00**	917	175	19.1	126
25			166	18.1	129
30			171	18.6	129
15			273	28.2	143
20	**2002/03**	968	270	27.9	151
25			277	28.6	153
30			285	29.4	165
15			170	23,3	81
20	**2006/07**	731	169	23.1	83
25			167	22.8	85
30			165	22.6	85
15			250	26.4	119
20	**2008/09**	948	245	25.8	124
25			247	26.1	127
30			240	25.3	128

According to the analyses of total precipitation values, total drainage discharge values and total duration of drainage discharge for different drainpipes spacing (*Table 3*), differences are noticeable in the quantity and duration of drainage discharge, both between the tested drainpipes spacing in each growing season and between the trial years. Differences in the quantity of drainage discharge between drainpipes spacing in a particular year are smaller than differences between years. There is a strong correlation between total precipitation and total drainage discharge (r=0.79 up to 0.85; *Figure 2*) and generally in case of higher precipitation, drainage discharge is higher, and vice versa (*Table 3*), but drainage discharge is dependent on many factors such as, the amount, frequency and intensity of precipitation, crop type and crop development stage, i.e. evapotranspiration.

The shortest duration of drainage discharge was recorded in each year at the drainpipes spacing of 15 m and the longest at drainpipe spacing of 30 m. According to *Petosic et al.* (1998) and *Tomic et al.* (2002), narrower drainpipe spacing and shorter duration of drainage discharge are more efficient.

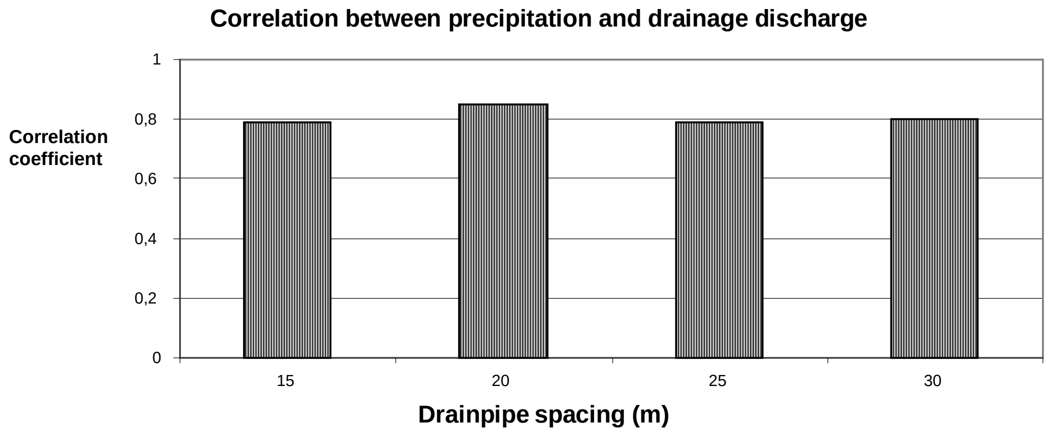

Figure 2 Correlation between precipitation and drainage discharge

Nitrogen leaching

Drainage water was sampled every day during the discharge period. Nitrates were determined spectrophotometrically by yellow colouring of phenol disulphonic acid (*APHA-AWWA-WPCF,* 1992).

Maximum nitrogen concentrations in drainage water from all drainpipes spacing variants during the trial period exceeded the concentration of 10 mg/L (*Table 4*).

Table 4 Maximum concentration of nitrogen (mg dm^{-3}) in drainage water

Spacing variants (m)	1991/92	1993/94	1996/97	1999/00	2002/03	2006/07	2008/09
15	32.82	29.15	20.05	18.15	34.32	23.12	28.42
20	30.93	29.03	20.81	19.24	33.19	23.18	28.12
25	31.67	29.13	20.34	20.21	34.71	24.59	27.23
30	30.63	29.07	19.91	18.43	33.58	23.53	27.05

Table 5 Average concentration of nitrogen (mg dm^{-3}) in drainage water

Spacing variants (m)	1991/92	1993/94	1996/97	1999/00	2002/03	2006/07	2008/09
15	16.25 a	12.90 a	10.21	9.51	17.37 b	12.15	13.90 a
20	15.95 b	12.22 b	10.36	8.99	17.70 a	12.33	13.71 a
25	15.67 b	12.88 a	10.58	9.54	17.81 a	12.74	12.57 b
30	15.26 c	11.95 c	10.51	9.47	17.82 a	11.78	12.65 b

Values marked by the same letter are not significantly different according to Duncan's test ($p=0.01$)

At maize grown the highest nitrogen concentrations in all drainpipes spacing were recorded in 1991/92 and 2002/03 (*Figure 3*), when higher fertilizer doses were applied (175 kg/ha and 164 kg N ha^{-1}, respectively) and higher precipitation (drainage discharge) was also recorded, especially in May and July (*Table 2*) after fertilization. The lowest nitrogen concentration (in all drainpipes spacing) was detected in 1999/00, when the lowest total drainage discharge of all trial years was determined, although it was not the year when the lowest fertilizer rates were applied. At winter wheat grown higher nitrogen concentrations was recorded in all variants in 2008/09 than in 2006/07, when higher fertilizer doses was applied (184 kg/ha) and higher precipitation (drainage discharge) was also recorded, especially in autumn after fertilization (*Table 2*). Average nitrogen concentration values in six years were in all variants above the allowable concentration, except in 1999/2000.

As observed in *Figure 3* for drainpipes spacing of 15 m, maximum nitrogen concentrations in drainage water (at maize grown) in all years were detected in spring, soon after sowing and topdressing, which generally coincided with precipitation maxima (i.e., after higher drainage discharge), except in 1996/97, when the highest drainage discharge occurred in September. Similar fluctuations of nitrogen concentration were observed in other drainpipe spacing variants.

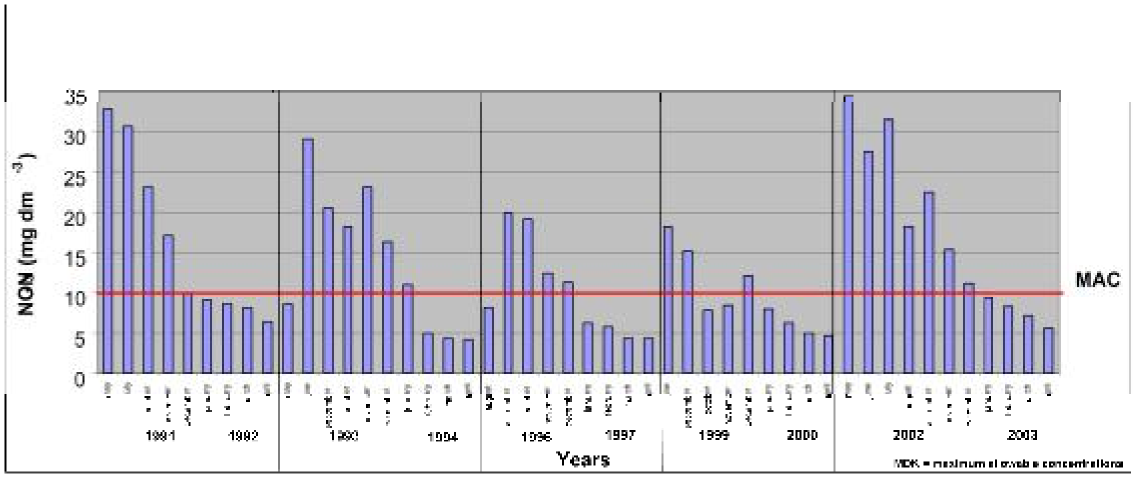

Figure 3 Fluctuation of maximum nitrogen concentration in drainage water at maize grown

As observed in *Figure 4* for drainpipes spacing of 15 m, maximum nitrogen concentrations in drainage water (at winter wheat grown) in both investigation years were detected in autumn, soon after sowing (fertilization).

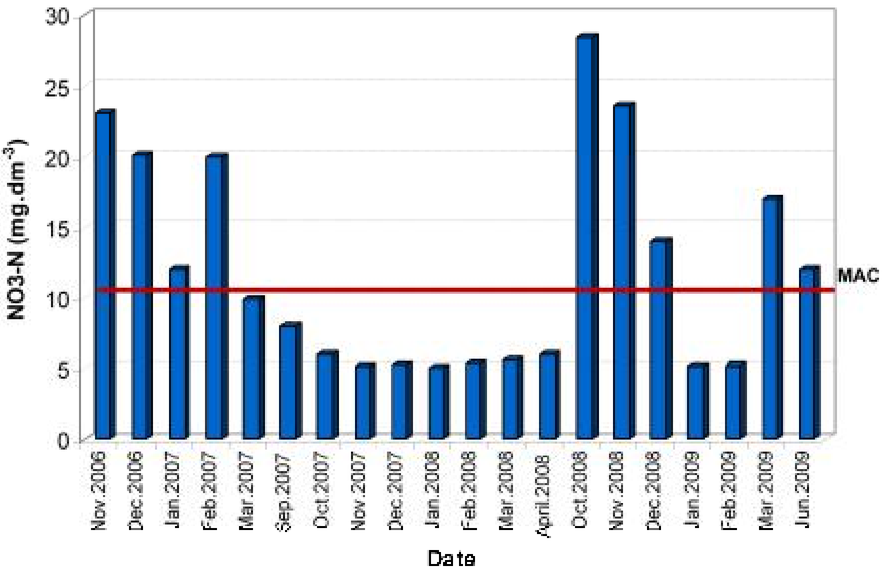

Figure 4 Fluctuation of maximum nitrogen concentration in drainage water at winter wheat grown

In the years 1991/92, 1993/94, 2002/03 (at maize grown) and 2008/09 (at winter wheat grown) there were significant differences in average concentration of nitrogen in drainage water between drainpipe spacing (p=0.05). Generally, the highest values are calculated for drainpipe spacing of 15 m and the lowest for drainpipe of 30 m. Nitrogen concentration in drainage water exceeded the MAC in three (1996/97) to seven months (1993/94)–Figure 3 (at maize grown) and five months in both years at winter wheat grown. Similar results for nitrogen concentrations in drainage water were obtained by *Kladivko et al.* (1991), Rossi et al. (1991), *Simunic et al.* (2002 and 2011) and *Bensa et al.* (2007). According to *Vidacek et al.* (1999), nitrate concentration in drainage water is dependent on the sampling time. Total annual quantities of nitrogen leached were estimated on the basis of the average monthly concentration and monthly quantity of drainage discharge.

According to the analyses of total annual quantity of nitrogen leached through drainage water (*Table 6*), there are differences (at maize grown) both between the tested drainpipes spacing in each year and between trial years. Differences between drainpipes spacing in the quantity of nitrogen leached in a particular year are smaller, but there are greater differences between years. Lower nitrogen leaching was recorded in all drainpipe spacing variants in the periods 1996/97 and 1999/00, when the quantity of drainage discharge was the lowest and lower nitrogen rates were applied than in 1991/92 and 2002/03.

Higher leaching occurred in the years 1991/92, 1993/94 and 2002/03 while either larger amount of nitrogen added with fertilization or higher drainage discharge. At winter wheat it was same about leaching of nitrogen. Differences between drainpipes spacing in the quantity of nitrogen leached in a particular year are small, but there are greater differences between years. Lower nitrogen leaching was recorded in all drainpipe spacing variants in year 2006/07, when the quantity of drainage discharge was lower and lower nitrogen rates was applied than in 2008/09.

At winter wheat grown in both years the highest leaching of nitrogen is recorded on drainpipes spacing of 15 m and the lowest on drainpipe of 30 m, but at maize grown it was different from year to year.

Table 6 Quantity of nitrogen leached (NL) through drainage water (kg ha^{-1}) and percentage of nitrogen leached relative to the total N added with fertilization

Spacing variants (m)	1991/92		1993/94		1996/97		1999/00		2002/03		2006/07		2008/09	
	NL	%	NL	%	NL	%	NL	%	NL	%	NL	%	NL	%
15	35.7	20.4	34.4	23.7	20.3	14.0	16.6	10.7	47.2	28.7	20.67	11.6	34.75	18.9
20	30.7	17.5	33.2	22.9	20.6	14.2	15.8	10.2	48.4	29.5	20.84	11.6	33.59	18.3
25	33.9	19.4	34.6	23.9	21.5	14.8	15.9	10.3	49.4	30.1	21.28	11.9	31.05	16.9
30	34.9	19.9	33.2	22.9	21.0	14.5	16.2	10.5	50.8	31.0	19.44	10.9	30.36	16.5

According to ***Mesic et al.*** (2007), the quantity of nitrogen leached is in linear correlation with the quantity of drainage discharge. These results (***Table 6***) are in accord with the results obtained by ***Skaggs and Gilliam*** (1985) and ***Klacic et al.*** (1998).

Different quantities of leached nitrogen are influenced by climate conditions. The total amount and distribution of precipitation (drainage discharge), crops grown, their development stages, as well as by the quantity of fertilizers applied and the time of their application. In this case, if there is higher amount of precipitation in spring or in autumn when maize and winter wheat needs less nitrogen and less water for its development, then it results in higher nitrate leaching.

If other crops (alfalfa) were grown, nitrate leaching would probably be different because of different root depth, different growth, etc.

Conclusions

The foregoing points to the conclusion that there were found differences in concentration of nitrogen between both tested drainpipes spacing in each year and between trial years. Differences between drainpipes spacing are smaller, but there are greater differences between years. There were statistically significant differences ($p=0.05$) in drainage water contamination with nitrates among the tested drainpipes spacing in the years 1991/92, 1993/94 and 2002/03 at maize grown and 2008/09 at winter wheat grown, but in years 1996/97 and 1999/00 at maize and 2006/07 at winter wheat there were no significant differences.

Maximum nitrogen concentrations in drainage water (at maize grown) in all years were detected in spring, soon after sowing and topdressing, which generally coincided with precipitation maxima (i.e., after higher drainage discharge) and maximum nitrogen concentrations in drainage water (at winter wheat grown) in both investigation years were detected in autumn, soon after sowing (fertilization) and after higher drainage discharge.

Nitrate levels in drainage water exceeded the MAC in all drainpipes spacing in three months (1999/00) to seven months (2002/03) at maize grown and five months in both years at winter wheat grown. The same concentration of nitrogen in drainage water it was and with leaching of nitrogen. Differences between drainpipes spacing in the quantity of nitrogen leached in a particular year are smaller, but there are greater differences between years.

The highest nitrate leaching occurred with the highest drainage discharge and with higher fertilization. At maize grown it was in year 2002/03 and winter wheat grown in year 2008/09.

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