Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 2712-2716
Received: 24-03-2019
Accepted: 25-04-2019

K Suseendran
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India

P Stalin
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India

C Kalaiyarasan
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India

S Jawahar
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India

S Ramesh
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India

Correspondence
K Suseendran
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Chidambaram, Tamil Nadu, India

Effect of herbicides for enhancing the productivity of transplanted rice (*Oryza sativa* L.) for Cauvery Delta region

K Suseendran, P Stalin, C Kalaiyarasan, S Jawahar and S Ramesh

Abstract
Field experiments was conducted to evaluate the performance of integrated weed management practices in growth, yield, nutrient uptake and economics on transplanted rice (*Oryza sativa* L.) during *Navarai* and *Kuruvai* season 2014 at the Experimental Farm, Department of Agronomy, Faculty of Agriculture, Annamalai University and at farmer's field Peruvarapur Village, Virudhachalam Taluk, Cuddalore District. The experiments consisted of fifteen treatments adopting in randomized block design and replicated thrice. The results revealed that early post emergence of Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT recorded higher plant height, LAI, DMP, grain yield, straw yield and nutrient uptake by crop and lower uptake by weeds. The net return and benefit-cost ratio were also higher under the application of early post emergence of Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT.

Keywords: Rice crop, IWM, growth, yield, nutrient uptake and economics

Introduction
Rice is one of the most important staple food crop of India which is cultivated under various ecosystems, *Viz*., transplanted, direct sown and rainfed situations. To meet the future food requirements of ever increasing population and maintain self sufficiency, the estimated rice production in India should be 350 million tonnes by 2020 AD. In transplanted rice, weed infestations not only reduce the grain yield up to 45% but also the quality of grain is also impaired. Mukherjee *et al*., (2008) [3] noticed that 20-40 DAT were the most critical period of crop-weed competition and found that weedy situation throughout the crop growth caused yield reduction to the tune of 57 to 61% in transplanted rice.
Weed free period during the critical period of competition is essential for obtaining optimum rice yield. This can be achieved by removing weeds manually, mechanically and through chemical sprays or by their combinations. This can be achieved by removing weeds manually, mechanically and through chemical sprays or by their combinations. Manual weeding is although an effective and most common method, however, scarcity and high wages of labour particularly during peak period of agricultural operations make this method uneconomic. Further, mechanical method of weed management is also time consuming, cost intensive, much tedious and also does not remove all the weeds. Weed management through herbicide application may be the best suited option. It also saves valuable time by covering more area in short period and is also cost effective. Raising cost of labour and their reduced availability has led to search for alternative methods such as herbicide use either alone or in combination with manual or mechanical weeding. The integration of chemical followed by mechanical weeding are cheaper and effective than hand weeding alone (Ali and Bhanumurthy, 1985) [1]. The integrated weed management (IWM) thus can play a vital role in transplanted rice cultivation, in order to reduce dependence on excessive chemical use, avoid environmental pollution and reduce weeding costs.

Materials and Methods
Experimental Site, Design and Layout
Field experiments were conducted during two seasons, *Viz*., Navarai and Kuruvai at the Experimental Farm, Department of Agronomy, Faculty of Agriculture, Annamalai University and at farmer's field Peruvarapur Village, Virudhachalam Taluk, Cuddalore District with clayey loam soil having the pH of 7.5 and 6.7 in Navarai and Kuruvai seasons, respectively. The experiment was laid out in a randomized block design and replicated thrice.

Weed control treatments

The treatments were T_1 - Bispyribac sodium 100g / LSC 20g a.i. ha^{-1} 20 DAT, T_2 - Bispyribac sodium 100g / LSC 20g a.i. ha^{-1} + 1 Hand weeding at 40 DAT, T_3 - Bispyribac sodium 100g / LSC 20g a.i. ha^{-1} + TRRW at 40 DAT, T_4-Metsulfuron methyl + Chlorimuron ethyl @ 4g a.i. ha^{-1} 20 DAT, T_5 - Metsulfuron methyl + Chlorimuron ethyl @ 4g a.i. ha^{-1} + 1 Hand weeding at 40 DAT, T_6 - Metsulfuron methyl + Chlorimuron ethyl @ 4g a.i. ha^{-1} + TRRW at 40 DAT, T_7- Bensulfuron methyl + Pretilachlor @ 60g a.i. ha^{-1} 3 DAT, T_8 - Bensulfuron methyl + Pretilachlor @ 60g a.i. ha^{-1} + 1 Hand weeding at 40 DAT, T_9 - Bensulfuron methyl + Pretilachlor @ 60g a.i. ha^{-1} + TRRW at 40 DAT, T_{10} - Pyrazosulfuron ethyl @ 30g a.i. ha^{-1} 3 DAT, T_{11} - Pyrazosulfuron ethyl @ 30g a.i. ha^{-1} + 1 Hand weeding at 40 DAT, T_{12} - Pyrazosulfuron ethyl @ 30g a.i. ha^{-1} + TRRW at 40 DAT. T_{13} - Hand weeding Twice at 20 and 40 DAT, T_{14} - Two Row Finger Type Rotary Weeder (TRRW) at 15, 25, 40 DAT, T_{15} - Unweeded Check. In manual method weeds were either pulled directly with hand or cut with sickle close to the ground surface. Mechanical hoeing was done with two row finger type rotary weeder. All the pre-emergence, early post emergence and post emergence herbicides were sprayed on 3 DAT and 20 DAT, respectively with adequate soil moisture. Knapsack hand sprayer fitted with T-jet nozzle was used for spraying herbicides.

Crop husbandry

The land was prepared by giving two ploughings each followed by planking with the help of a tractor drawn cultivator to achieve the fine seed bed. A fertilizer dose of 120: 38: 38 kg N.P.K. ha^{-1} in the form of urea, single super phosphate and sulphate of potash was applied to each experimental unit. The P and K with 1/3rd of N was applied at sowing while the remaining dose of N was applied in two splits i.e., 30 and 55 days after sowing. Zinc sulphate (20%) was applied @ 25 kg ha^{-1}. Seed rate of rice was 80 kg ha^{-1}was followed. The seeds were treated with carbendazim @ 2 g kg^{-1} of seeds. After 24 hours the seeds were treated with *Azospirillum* @ 600 g ha^{-1} of seeds. The seed was soaked in water for 24 hours before sowing and then kept under shade in the form of a heap covered with a gunny bag for 36 hours and for allowed sprouting. Spacing of 22.5 X 22.5 cm was adopted. First irrigation was given at 4 days after seeding and the same interval was maintained until two weeks after sowing. Subsequently, the irrigation was applied after weekly interval. The crop was harvested at full physiological maturity, sun-dried for a week and threshed manually.

Results and Discussion

Nutrient removal by weeds (kg ha^{-1})

Among the various herbicides tested, application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) recorded the lowest nutrient removal by weeds of 12.86, 7.34 and 9.18 kg N, P and K ha^{-1} during Navarai 15.10, 9.44 and 15.20 kg N, P and K ha^{-1} during Kuruvai, respectively. The highest amount of nutrient removal by weeds (49.36, 19.78, 31.42 and 52.67, 21.36 and 39.14 kg N, P and K ha^{-1}) during Navarai and Kuruvai, respectively was observed under unweeded control (T_{15}). The pattern of nutrient removal by weeds showed that where ever effective weed control was possible, the nutrient loss due to weeds was minimum. The loss of nutrients by weeds varied with intensity of weeds and weed dry matter accumulation. The nutrient removal by weeds was maximum under unweeded control due to higher weed population and weed biomass accumulation. However, application of early post emergence herbicide Bispyribac sodium 100g/LSC 20 g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder (TRRW) registered lesser nutrient removal. Rana and Angiras (1999) [5] confirmed that N, P and K removal by weeds was limited in herbicide applied plots when compared to unweeded control. Due to uncontrolled weed growth, the removal of N, P and K by the weeds was the highest in the unweeded check which resulted in increased drymatter production of weeds.

Table 1: Effect of weed management practices on nutrient removal by weeds (kg ha^{-1})

Treatment	Nutrient removal by weeds					
	Navarai *Season*			Kuruvai *Season*		
	N	P	K	N	P	K
T_1	38.19	15.53	25.49	41.98	17.63	31.75
T_2	17.68	9.68	13.36	20.81	12.18	18.97
T_3	12.86	7.34	9.18	15.10	9.44	15.20
T_4	40.48	16.15	26.90	44.63	18.30	33.31
T_5	26.99	13.15	19.85	31.39	14.92	25.36
T_6	29.28	13.73	21.25	34.03	15.59	26.95
T_7	42.80	16.75	28.29	47.25	18.98	34.92
T_8	20.00	10.30	14.75	23.46	12.84	20.52
T_9	22.30	10.91	16.13	26.10	13.50	22.10
T_{10}	45.10	17.34	29.70	49.88	19.61	36.51
T_{11}	31.59	14.33	22.67	36.66	16.22	28.53
T_{12}	33.86	14.94	23.98	39.28	16.91	30.10
T_{13}	24.57	11.40	17.54	28.70	14.18	23.70
T_{14}	15.24	8.05	11.57	17.97	10.32	17.32
T_{15}	49.36	19.78	31.42	52.67	21.36	39.14
S.Ed	1.08	0.29	0.66	1.24	0.32	0.75
CD(P=0.05)	2.33	0.63	1.43	2.67	0.70	1.62

Nutrient uptake by crop (kg ha^{-1})

Among the various treatments, application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) recorded the highest nutrient uptake by rice crop of 105.12, 45.53 and 98.56 kg ha^{-1} N, P and K during Navarai and 102.28, 41.58 and 94.42 kg ha^{-1} N, P and K ha^{-1} during Kuruvai season, respectively. The lowest nutrient uptake by rice crop was recorded in unweeded control treatment with the values of 72.24, 26.23 and 71.30 kg N, P and K ha^{-1} in Navarai and 70.18, 25.04 and 70.14 kg N, P and K ha^{-1} in Kuruvai, seasons, respectively. Balasubramanian *et al.*, (1996) [2] stated that unweeded control caused significant higher nutrient drain, which might other wise utilized by the crop. This was due to poor crop stand in the initial stages and decreased tiller production.

Table 2: Effect of weed management practices on nutrient uptake by rice (kg ha^{-1})

Treatment	Nutrient uptake by rice					
	Navarai *Season*			Kuruvai *Season*		
	N	P	K	N	P	K
T_1	82.37	32.10	80.43	80.97	30.34	78.56
T_2	100.37	42.69	94.36	97.92	39.28	91.15
T_3	105.12	45.53	98.56	102.28	41.58	94.42
T_4	80.15	30.78	78.76	78.88	29.29	76.99
T_5	91.34	37.42	87.35	89.46	34.58	84.87
T_6	89.17	36.10	85.64	87.38	33.63	83.33
T_7	77.92	29.47	77.10	76.77	28.22	75.43
T_8	98.13	41.38	92.63	95.83	38.22	89.61
T_9	95.94	40.09	90.91	93.72	37.17	88.08
T_{10}	75.73	28.18	75.38	74.69	27.14	73.89
T_{11}	86.93	34.79	83.95	85.27	32.55	81.79
T_{12}	84.74	33.51	82.27	83.15	31.49	80.21
T_{13}	93.72	38.81	89.18	91.63	36.11	86.51
T_{14}	102.76	44.12	96.18	100.11	40.45	92.78
T_{15}	72.24	26.23	71.30	70.18	25.04	70.14
S.Ed	1.05	0.62	0.81	0.99	0.51	0.73
CD(P=0.05)	2.27	1.35	1.76	2.14	1.10	1.59

Post harvest soil available nutrients (N, P and K kg ha^{-1})

Among the various treatments tested, application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) recorded highest available nutrients in the post harvest soil *viz.*, 235.64, 19.54 and 296.44 kg N, P and K ha^{-1} during Navarai and 206.41, 13.24, and 224.58 kg N, P and K ha^{-1} during Kuruvai season, respectively. The lowest available nutrients in the post harvest soil were recorded in unweeded control (T_{15}) with value of 215.21, 11.78 and 268.34 kg N, P and K ha^{-1} in Navarai and 184.65, 6.15 and 200.05 kg N, P and K ha^{-1} in Kuruvai season, respectively.

Table 3: Effect of weed management practices post harvest soil available nutrients (kg ha^{-1})

Treatment	Post harvest soil available nutrients (kg ha^{-1})					
	Navarai season			Kuruvai season		
	N	P	K	N	P	K
T_1	219.90	14.11	276.66	191.01	8.19	207.74
T_2	232.34	18.27	292.31	203.20	12.11	221.06
T_3	235.64	19.54	296.44	206.41	13.24	224.58
T_4	218.25	13.63	274.75	189.51	7.71	206.08
T_5	226.17	16.17	284.47	197.10	10.15	214.37
T_6	224.63	15.68	282.56	195.61	9.70	212.73
T_7	216.72	13.16	272.83	187.99	7.23	204.43
T_8	230.81	17.78	290.40	201.71	11.62	219.41
T_9	229.38	17.31	288.48	200.22	11.15	217.75
T_{10}	215.21	12.67	270.92	186.50	6.76	202.80
T_{11}	223.10	15.20	280.63	194.10	9.23	211.11
T_{12}	221.58	14.73	278.71	192.58	8.77	209.45
T_{13}	227.84	16.83	286.54	198.71	10.69	216.10
T_{14}	234.01	18.91	294.38	204.83	12.68	222.78
T_{15}	215.21	11.78	268.34	184.65	6.15	200.05
S.Ed	0.73	0.25	0.91	0.71	0.23	0.78
CD(P=0.05)	1.59	0.55	1.99	1.54	0.51	1.69

Effect of herbicides on Growth and yield attributes on rice

Plant height

Among the various treatments, early post emergence herbicide application of Bispyribac sodium 100g/LSC 20g a.i. ha 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly registered the tallest plant height of 55.50, 78.95, and 96.98 cm on 30, 60 DAT and at harvest stages during Navarai and 53.70, 75.99 and 94.36 cm at respective stages of crop growth during Kuruvai seasons, respectively. The least values of plant height were recorded in unweeded control (T_{15}) at all the stages of crop growth. This might be due to better weed control throughout growth stages of rice and better availability of all resources *viz.*, light, moisture, space and nutrients to rice crop.

Leaf area index

The treatments altered the leaf area index at flowering of crop significantly during the both the seasons. Application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly registered the highest leaf area index of 6.90 in Navarai and 6.48 during Kuruvai seasons, respectively. The least LAI was noticed in unweeded control plot (T_{15}) with least LAI of 3.12 and 3.05 at flowering stage, respectively.

Number of tillers hill^{-1}

Among the various treatments, the application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly recorded the highest number of tiller hill^{-1} (18.86 in Navarai and 16.96 in Kuruvai). The lower number of tillers hill^{-1} (9.10 and 10.15, respectively) was recorded under unweeded control (T_{15}).

Dry matter production (kg ha^{-1})

Application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly recorded the highest crop dry matter production of 6968, 10895 and 13521 kg ha^{-1} during Navarai and 6869, 10780 and 13390 kg ha^{-1} during Kuruvai on 30, 60 DAT and at harvest, respectively. The lowest dry matter production of 1310, 4030, and 7151 kg ha^{-1} on 30, 60 DAT and at harvest was recorded during Navarai and 1240, 4011 and 6897 kg ha^{-1} on 30, 60 DAT and at harvest during Kuruvai were recorded in unweeded control treatment. Higher nutrient removal reduced the tiller numbers resulting in the lowest dry matter production of crops under unweeded check. This observation was in accordance with the reports of Singh *et al.*, (2004).

Effect of weed management practices on Yield attributes

Number of panicles m^{-2}

Among the different weed management practices, application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly registered the highest number of panicle m^{-2} (526 in Navarai and 516 in Kuruvai). The lowest number of penicles (330 and 315 m^{-2}) was recorded in Navarai and Kuruvai season, respectively, in unweeded control treatment (T_{15}). Similar results of higher yield attributes of transplanted rice under bispyribac-sodium application were reported by Yadav *et al*., (2009).

Number of filled grains panicle^{-1}

Application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly registered the maximum number of filled grains panicle^{-1} (80.31 in Navarai and 76.22 in Kuruvai, respectively). The minimum number of filled grains panicle^{-1} of 56.02 and 55.40 was registered during both the seasons, respectively.

Table 4: Influence of weed management practices on growth components on 60 DAT

Treatments	Growth components					
	Navarai *season*			Kuruvai *season*		
	Plant height	LAI	DMP	Plant height	LAI	DMP
T_1	58.33	4.21	6135	56.48	4.11	6058
T_2	74.51	6.16	9925	71.95	5.91	9838
T_3	78.95	6.90	10895	75.99	6.48	10780
T_4	56.44	3.99	5664	54.51	3.93	5599
T_5	66.45	5.15	8026	64.28	5.05	7996
T_6	64.50	4.93	7557	62.31	4.85	7539
T_7	54.39	3.78	5195	52.63	3.71	5142
T_8	72.51	5.97	9454	70.10	5.72	9381
T_9	70.55	5.79	8984	68.22	5.52	8923
T_{10}	52.33	3.57	4728	50.74	3.51	4684
T_{11}	62.48	4.74	7085	60.42	4.66	7079
T_{12}	60.51	4.56	6619	58.55	4.45	6619
T_{13}	68.61	5.57	8517	66.33	5.34	8464
T_{14}	76.78	6.57	10408	73.99	6.20	10310
T_{15}	49.21	3.12	4030	47.88	3.05	4011
S.Ed	0.97	0.11	220	0.92	0.11	214
CD (P=0.05)	2.10	0.25	478	1.98	0.23	461

Grain yield (kg ha^{-1})

Among the treatments, application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly registered the maximum grain yield of 5716 kg ha^{-1} during Navarai and 5606 kg ha^{-1} during Kuruvai. The lower grain yield of 2400 kg ha^{-1} and 2295 kg ha^{-1} was recorded in unweeded control treatment (T_{15}) at Navarai and Kuruvai seasons, respectively. This was attributed to efficient and broad spectrum of weed control and favourable condition created through the efficient weed control that resulted in lesser weed competition between the crops and weeds. Murali *et al.*, (2012) obtained similar grain yield of transplanted rice under bispyribac-sodium at both the doses of 50 and 35 g/ha.

Table 5: Effect of weed control treatments on grain yield and straw yield (kg ha^{-1})

Treatments	Yield components					
	Navarai *season*			Kuruvai *season*		
	No.of panicles	Grain yield	Straw yield	No.of panicles	Grain yied (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	388	3613	5921	381	3518	5492
T_2	485	5120	6812	478	5065	6782
T_3	526	5716	7416	516	5606	7191
T_4	377	3504	5413	373	3405	5321
T_5	438	4398	6210	428	4269	6201
T_6	429	4214	6118	420	4116	6003
T_7	365	3401	5316	362	3312	5203
T_8	478	4908	6705	469	4878	6610
T_9	469	4805	6614	458	4751	6532
T_{10}	356	3310	5225	352	3215	5010
T_{11}	419	4103	5921	415	3910	5806
T_{12}	407	3915	5808	406	3821	5698
T_{13}	461	4700	6515	449	4601	6405
T_{14}	505	5413	7110	500	5337	6987
T_{15}	330	2400	4250	315	2295	4120
S.Ed	6.97	137	108	6.51	123	103
CD (P=0.05)	15	282	222	14	265	201

Straw yield (kg ha^{-1})

Straw yield was significantly influenced by various treatments. The application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) significantly recorded higher straw yield of 7416 kg ha^{-1} during Navarai and 7191 kg ha^{-1} during Kuruvai seasons, respectively. The lowest straw yield of 4250 kg ha^{-1} and 4120 kg ha^{-1} was recorded in unweeded control treatment (T_{15}) in Navarai and Kuruvai seasons, respectively.

Economics

Application of early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) registered the maximum net income of Rs 54427 ha^{-1} and return rupee^{-1} invested of 2.64 during Navarai and net income of Rs 51857 ha^{-1} and return rupee^{-1} invested of ` 2.53 during Kuruvai. The unweeded control recorded the minimum net income Rs 6745 ha^{-1} and Rs 4340 ha^{-1} and return rupee^{-1} invested 1.21 and 1.13 during Navarai and Kuruvai, seasons respectively. The unweeded control registered the lowest net income and return rupee^{-1} invested due to poor grain yield and experienced severe weed competition throughout the crop growth period.

Table 6: Economics of rice

Treatments	Navarai *Season*		Kuruvai *Season*	
	Net income (Rs. ha^{-1})	BCR	Net income (Rs. ha^{-1})	BCR
T_1	23879	1.73	21315	1.63
T_2	44640	2.31	42871	2.23
T_3	54427	2.64	51857	2.53
T_4	22694	1.71	20411	1.62
T_5	34779	2.05	31995	1.94
T_6	32950	2.02	30658	1.92
T_7	19339	1.57	17175	1.49
T_8	40598	2.16	39033	2.08
T_9	39904	2.17	32261	2.09
T_{10}	19662	1.61	17312	1.52
T_{11}	30232	1.91	26447	1.77
T_{12}	28326	1.87	26095	1.78
T_{13}	38755	2.15	36126	2.04
T_{14}	50621	2.56	48629	2.47
T_{15}	6745	1.21	4340	1.13

Conclusion

Based on the above results of the experiment, it can be concluded that, early post emergence herbicide Bispyribac sodium 100g/LSC 20g a.i. ha^{-1} on 20 DAT followed by two row finger type rotary weeder at 40 DAT (T_3) proved practically more convenient and economically best feasible integrated weed management practices for transplanted rice.

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