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The Optimum Dose of Nitrogen, Phosporus, and Potassium to Improve Soybean (*Glycine max* (L) Merr) Productivity on *Kayu Putih* (*Melaleuca cajuputi*) Stands

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ABSTRACT

It was necessary to obtain optimum dose of nitrogen, phosphorus, and potassium obtained through fertilisation in order to improve productivity in the intercropping. *Kayu putih* tree was cultivated in Yogyakarta for oil production, and the inter-row was designed for intercropping plants, including soybean. The objective of present study was to obtain optimum dose of urea, SP-36, and KCl for soybean intercropped with kayu putih. The experiment was conducted in Menggoran Forest Resort (RPH Menggoran), Playen Forest Section (BDH Playen), Yogyakarta Forest Management District (KPH Yogyakarta) using split-split plot design. The main plot was urea, subplot was SP-36, and sub-subplot was KCl. Fertilisation consisted of three levels (0, 25, 50 kg ha^{-1} of urea), (0, 150, 300 kg ha^{-1} of SP-36) and (0, 75, 150 kg ha^{-1} of KCl). The results showed that application of 50 kg ha^{-1} urea, 300 kg. ha^{-1} SP-36, and 150 kg. ha^{-1} KCl increased N, P, K uptake per hectare as much as 16.23 kg N ha^{-1}, 86.27 kg P ha^{-1}, 40.02 kg K ha^{-1}, respectively. There was positive interaction between urea and SP-36, SP-36 and KCl at leaf area, photosynthetic rate, number of seeds per plants, seed weight per plants, and seed weight per hectare. Under kayu putih intercropping, optimum dosage of urea, SP-36 and KCl were 0, 298.03 and 87.12 kg ha^{-1}, respectively. These combination enabled to produce maximum seed weight of 2.01 tons. ha^{-1}.

Keywords: *Kayu Putih*, Optimum Dose of Nitrogen, Phosphorus and Potassium, Soybean Fertilisers, Soybean Productivity

INTRODUCTION

Soybean (*Glycine max* (L) Merr) is a popular seasonal crop and is cultivated by Indonesian farmers because of its role in public life. A lot of processed foods are derived from soybeans raw materials, such as *tempe*, *kecap*, *tauco*, and others. More diverse processed foods derived from soybean raw material are expected to increase soybean demand among the public in the next years.

Average soybean projected demand issued by National Development Planning Agency in year 2012-2019 is approximately 2,846,250 tons. This figure is still very high due to the projected domestic soybean production only reached 924.250 tons in 2012-2019. There is 1,922,000 tons deficit (BPPN, 2013). Lower production of soybeans in the country is caused by: 1) the lack of area for soybean cultivation, and 2) low productivity of soybeans grown by farmers. Reduction in agricultural land is due to land convertion and the potential for agriculture to non-agricultural activities, land convertion from soybean cultivation replaced with other crops. Average nationwide productivity of soybean from in 1993-2015 ranged from 1.1 to 1.5 tons ha^{-1}. To overcome this problem, land intensification and balanced fertilisation can be used (BPS, 2015). Popularity of soybean in agroforestry is increasing, as proven by the implementation of agroforestry system done by farmers in Gunungkidul regency by planting soybeans between *kayu putih* stands.

Intercropping is a soil management technique by combining tree and seasonal crop components in the same space and time. Intercropping is one of forestry programs aimed to maintain food security of the community around the forest. Intercropping on *kayu putih* forests in the context of food security is an important part of the forest movement for food (Suryanto *et al*., 2017). Several researches have been conducted, such by Ceunfin *et al*. (2015) and Purba *et al*. (2015) who examined the planting distance and zone between black soybean (*Glycine soja* L.) Merrit) and maize (*Zea mays*) in intercropping of *kayu putih* and the effect of mycorrhizal application on the growth and yield of soybean (Sinaga *et al*., 2016). There was no negative effects of *kayu putih* on seasonal crops in the field, such as shade effects and alelopati (Ceunfin *et al*., 2015). Fertilisation is done by farmers to improve crop productivity. However, the fertilisation activities done by farmers sometimes do not refers to the recommended dosage by local department of agriculture, so its use is relatively according to forecasts and unbalanced. The use of fertiliser with a too high or too low dosage will lead to a decrease in plant responses.

Nitrogen, phosphorus, and potassium are macro nutrient which are contained in fertilisers and are absolutely needed by plants. Gardner *et al*. (1991) described some of the symptoms shown by plants for excessive nitrogen which can cause greener leaves, denser leaves, a decrease in flower production, and prone to pests and disease. Meanwhile nitrogen deficiency would interfere with growth process, the plants become stunted, the leaves turn yellow, yield and plant dry weight are reduced. Excessive phosphorus will interfere with the absorption of micronutrients, such as iron (Fe), copper (Cu), and zinc (Zn). Phosphorus deficiency can cause purplish colored older leaves tend to be gray, brown colored edges of the leaves turn, the growth of small leaves, and slow growth phase, as well as stunted plants. Potassium is an important nutrient for plants. Application potassium to the plant will cause the absorption of calcium (Ca^{2+}) and magnesium (Mg^{2+}) to be disturbed. Its deficiency might show responses, such as like flowers fall off easily, the leaves at the bottom to be dry or there are spots, scorched leaves, and leaf edges curl downward.

Through a balanced fertilisation, soybean productivity is expected to be improved and could provide information to farmers. Thus this study aims to obtain the optimum dose of nitrogen, phosphorus, and potassium to improve soybean productivity on *kayu putih* stands.

MATERIALS AND METHODS

The research was conducted from February to May 2015 in Menggoran Forest Resort (RPH Menggoran), Playen Forest Section (BDH Playen), Yogyakarta Forest Management District (KPH Yogyakarta). The altitude of the area was 177 m above sea level and the soybean used was Grobogan varieties. *Kayu putih* in the study site existing and planted by KPH Yogyakarta with 7-17 years age range and planting distance of 4 x 2 m. *Kayu putih* cultivation system one of them with pruning the canopy every year for harvest. This field experiment was a response surface estimation to urea, SP-36, and KCl which was a step to obtain the optimum dose for urea, SP-36, and KCl for soybean cultivation.

The field experiment was done using split-split plot design, i.e: 1) urea as main plot, 2) SP-36 as subplots, and 3) KCl as sub-subplots, each consisting of three levels (0, 25, 50 kg ha^{-1} of urea), (0, 150, 300 kg ha^{-1} of SP-36) and (0, 75, 150 kg ha^{-1} of KCl). The dosage refered to a recommendation from Institute for Agricultural Technology Special Region of Yogyakarta (BPTP, 2008). Observations included: 1) soil characteristics, 2) growth components (leaf area, light interception, transpiration rate and photosynthetic rate, N, P, K uptake per hectare), 3) yield component (number of seeds per plants, seed weight per plants and seed weight per hectare). Obtained data from observations were analyzed using Analysis of Variance (ANOVA) according to split-split plot design using *SAS software* for Windows release 9.1. When differences resulted were significant, individual means were compared using the Duncan's Multiple Range Test (DMRT) at 5% levels

RESULT AND DISCUSSION

Soil Characteristics

Based on soil characteristics observation (Table 1), neutral soil pH with the organic matter content and C-organic in the poor state. The lack of such material in the soil would affect the availability of N. Buckman and Brady (1969) explained that N nutrient joined with organic ingredients and changing very complex, protein was converted from the decomposition into nitrate (NO_3^-) can then be utilized by microorganisms and plants or lost through the leaching process and

Table 1. Soil chemical properties before sowing

Parameters	Mean value	Rating
pH H^2O	7.2	Neutral
C-organic (%)	1.27	Low
Organic matter (%)	2.19	Low
N-kjeldhal (%)	0.11	Low
P-olsen (%)	28.43	Moderate
Exch. K^+ (%)	16.71	Low
Exch. Ca^{2+} (cmol(+)kg^{-1})	45.35	Very high
CEC (cmol(+)kg^{-1})	55.51	Very high
Base saturation (%)	85.84	Very high
Texture		Heavy clay

Source: Soil Laboratory of Agriculture Faculty, UGM.

Table 2. Mean growth component of each treatment

Treatment	Growth Component			
	Leaf area (cm^{-2})	Light interception (%)	Transpiration rate (mmol $H_2O.m^{-2}.s^{-1}$)	Photosynthetic rate (μmol CO_2. $m^{-2}.s^{-1}$)
Urea (kg. ha^{-1})				
0	1647.60 a	45.25 a	0.56 a	26.75 a
25	1975.00 a	44.14 a	0.72 a	31.83 a
50	2022.70 a	43.66 a	0.70 a	34.59 a
SP-36 (kg. ha^{-1})				
0	1582.30 b	45.20 ab	0.57 b	25.99 c
150	1843.10 b	38.40 b	0.46 b	30.80 b
300	2220.00 a	49.46 a	0.96 a	36.38 a
KCl (kg. ha^{-1})				
0	1833.10 a	47.36 a	0.67 a	30.60 a
75	1738.00 a	45.87 a	0.55 a	28.92 a
150	2074.30 a	39.82 a	0.77 a	33.65 a
Mean	1881.81	44.35	0.66	31.05
Urea*SP-36	(+)	(-)	(-)	(+)
Urea*KCl	(-)	(-)	(-)	(-)
SP-36*KCl	(-)	(-)	(-)	(-)
Urea*SP-36*KCl	(-)	(-)	(-)	(-)

Remarks: Number followed by letter the same in the column indicated no significant difference according to DMRT at 5% levels. Sign (+) and (-) indicated an interaction and no interaction found between the factors tested.

Table 3. The interaction of urea and SP-36 fertiliser on leaf area and photosynthetic rate

Urea (kg. ha^{-1})	SP-36 (kg. ha^{-1})			Mean
	0	150	300	
leaf area	....	cm^{-2}	....	
0	1204.90 d	1759.30 bcd	1978.80 abc	1647.60
25	1526.90 cd	2190.60 ab	2207.70 ab	1975.00
50	2015.30 abc	1579.50 bcd	2473.40 a	2022.70
Mean	1582.30	1843.10	2220.00	(+)
Photosynthetic rate	....	μmol CO2. $m^{-2}.s^{-1}$	....	
0	19.69 d	28.64 bcd	31.92 abc	26.75
25	23.52 cd	35.97 ab	36.00 ab	31.83
50	34.76 ab	27.78 bcd	41.22 a	34.59
Mean	25.99	30.80	36.38	(+)

Remarks : Number followed by letter the same in the column indicated there was no significant difference according to DMRT at 5% levels. Sign (+) indicated there was an interaction found between the factors tested.

evaporates into a gas (N_2). Human activities in agriculture also played a role in the process of losing N source in the soil (Chen *et al*., 2014; Qiao *et al*., 2015; Zhu *et al*., 2015). P and K^+ soil content related to the type of cation and soil texture. Parent material originating from limestone contained Ca_2^+ and base saturation was very high. P nutrient in the soil was very easily adsorbed by Ca_2^+, forming a phosphate compound (PO_4^{3-}) or apatite ($Ca_5(PO_4)_3$), which was unavailable for plants. There was a relationship between phosphate and lime content. Soil containing phosphates were usually alkaline, so it could not be absorbed by plants (Darmawijaya, 1990). This relationship was also confirmed from the research conducted by Daly *et al*. (2015) who found a correlation between the content of Ca^{2+} and P availability in the soil.

A low content of K^+ and a high CEC soil was caused by the adsorption of heavy clay minerals type 2:1. The main mineral in clay soils was dominated by smectite minerals type 2:1, so as to adsorbed K^+

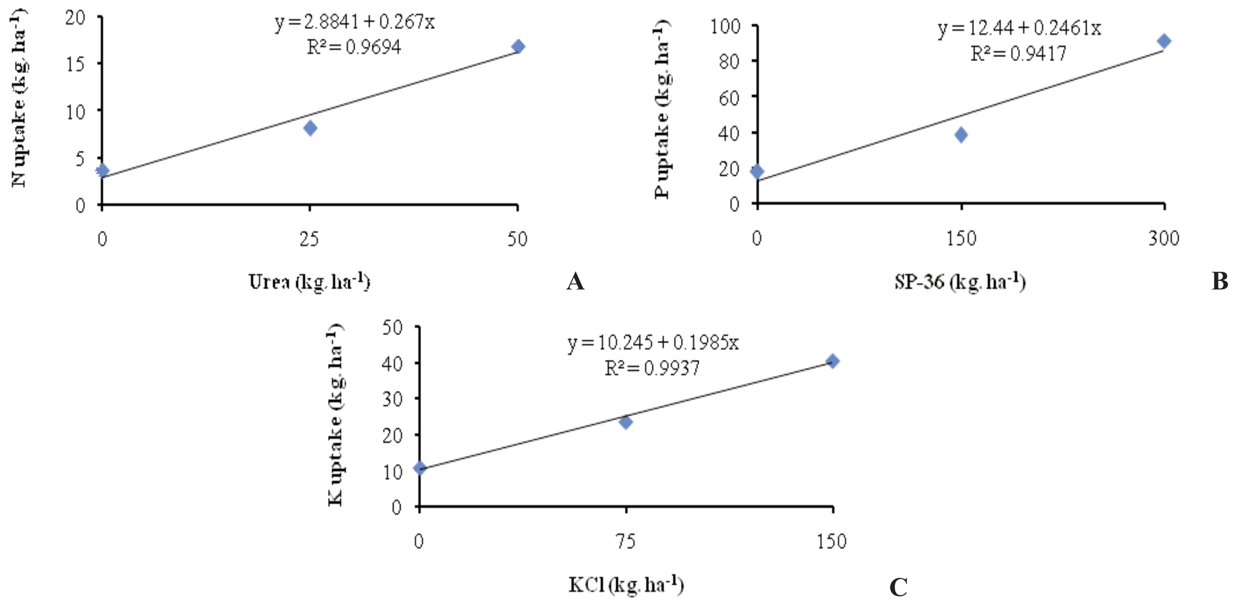

Figure 1. The relationship between dose (A) urea, (B) SP-36, (C) KCl and N, P, K uptake per hectare.

on the clay surface and raise the soil CEC (Prasetyo, 2007).

Growth Component and N, P, K Uptake by Plants

Observation of the growth components showed that the use of SP-36 fertiliser dosage of 300 kg ha^{-1} had a significantly difference compared with SP-36 fertiliser treatment with 0 and 150 kg ha^{-1} dosage for leaf area, light interception, transpiration rate, and photosynthetic rate (Table 2). There was a positive interaction among urea and SP-36 and leaf area and photosynthetic rate. Fertilisation performed on soybean with 300 kg. ha^{-1} of SP-36 had a positive effect on growth component. Leaf area would increase when the availability of P was fulfilled. The role of P in the growth process was as a constituent of plant tissues, such as nucleic acids, phospholipids, and fitin (Tisdale, 1990). On wheat, P deficiency would cause a disruption in physiological processes and plant growth, especially in leaves (Fernandez *et al*., 2014).

There was interaction between urea and SP-36 fertiliser treatment (Table 3). The combination resulted in a positive interaction for leaf area and photosynthetic rate. In leaf area and photosynthetic rate, the combination of 50 kg ha^{-1} urea and 300 kg ha^{-1} SP-36 showed a significant difference compared with the combination of urea and SP-36 0 kg ha^{-1} dosage.

Interactions that occurred between leaf area and photosynthetic rate with urea and SP-36 treatments was predicted to have a correlation with the uptake of N and P (Figure 1) through an increase in the rate of transpiration. Research conducted by Chiezey *et al*. (2009) showed there was an increase in soybean leaf area, transpiration rate, and photosynthetic rate through P fertilisation. Within plant tissues, nitrogen and phosphorus played a role in the formation of ATP and ADP at the process of energy transfer in photosynthetic. When one of these elements were not available, it would affect energy transfer process in photosynthesis (Gardner *et al*., 1991).

Based on the results of correlation analysis (Table 4), the relationships between transpiration rate (r = 0.46 **), N uptake (r = 0.41 **), P uptake (r = 0.50 **), K uptake (r = 0.36 **) at the photosynthetic rate could be obtained.

Statistical analysis of soybean yield components results showed that 300 and 150 kg ha^{-1} SP-36 was significantly different compared with 0 kg ha^{-1} SP-36 for number of seeds per plants, seed weight per plants, and seed weight per hectare (Table 5).

Seed was the sink organ for the photosynthetic product. Assimilation formed in the vegetative phase would then be distributed to the establishment of seed pods and filling. In sorghum, seed filling process was influenced by the availability of N and P in vegetative phase (Goldsworthy and Fisher,

Table 4. The correlation among variables

	TR	*NU*	*PU*	*KU*	*PR*
TR	1				
NU	0.21^{ns}	1			
PU	0.43**	0.24*	1		
KU	0.24*	0.33**	0.36**	1	
PR	0.46**	0.41**	0.50**	0.36**	1

Remarks: Number followed by (^{ns}) and (*) indicated no significant and significant difference at 5% levels, numbers followed by (**) indicated significant difference at 1% levels. *TR* = Transpiration rate; *NU* = N uptake; *PU* = P uptake; *KU* = K uptake; *PR* = Photosynthetic rate.

Table 5. Mean yield component of each treatment

Treatment	Yield Component		
	Number of seeds/plants	Seed weight/plants (g)	Seed weight/hectare (tons)
Urea (kg. ha^{-1})			
0	36.59 a	5.92 a	1.54 a
25	42.12 a	6.89 a	1.79 a
50	40.66 a	6.78 a	1.75 a
SP-36 (kg. ha^{-1})			
0	35.43 b	5.71 b	1.47 b
150	41.38 a	6.64 a	1.73 a
300	42.56 a	7.24 a	1.88 a
KCl (kg. ha^{-1})			
0	38.50 a	6.26 a	1.58 a
75	39.16 a	6.61 a	1.73 a
150	41.70 a	6.72 a	1.78 a
Mean	39.79	6.53	1.69
Urea*SP-36	(-)	(-)	(-)
Urea*KCl	(-)	(-)	(-)
SP-36*KCl	(+)	(+)	(+)
Urea*SP-36*KCl	(-)	(-)	(-)

Remarks: Number followed by letter the same in the column indicated no significant difference according to DMRT at 5% levels. Sign (+) and (-) indicated there was an interaction and no interaction found between the factors tested.

1996). Estimated remobilization and translocation process from source to sink which involved N and P in the plant tissue was around 62% and 65% (Brant and Chen, 2015). So when the availability of these elements at the vegetative phase was fulfilled, they would be used for establishment and seed filling process. The increase in the rate of photosynthetic at a vegetative stage had a positive impact on number of seeds and seed weight.

There was interaction found between the combination of SP-36 and KCl fertiliser (Table 6). The combination resulted in a positive interaction in number of seeds per plants, seed weight per plants, and seed weight per hectare. In number of seeds per plants, seed weight per plants, and seed weight per hectare, the combination of SP-36 dose 0 kg ha^{-1} and KCl 0 kg ha^{-1} and 150 kg. ha^{-1} did not significantly different. However, both combinations were significantly different compared with SP-36 of 300 kg ha^{-1} dosage and KCl of 75 kg. ha^{-1} dosage. The interaction occured in fertilisation treatment of SP-36 and KCl was because of the role of these elements in plants. In the majority of plant species, P and K was found in large quantities in the seed. Through fertilisation using P and K, soybean seed yield could be increased (Xiang *et al*., 2012). P stimulated the establishment of seed, while the functions of K was in assimilate transportation from leaf to seed (Gardner *et al*., 1991).

Seed weight per hectare are obtained through the interaction between fertilization SP-36 and KCl (Table 6) is used as a guide to get a dose of fertilizer optimum soybeans. The equation was Y(seed weight per hectare) = $1.39^{**} + 0.0055^{ns}$ K (kg KCl per ha) + 0.0019^{ns} P (kg SP-36 per ha) – 0.000035^{ns} K^2 + 0.0000026^{ns} PK – 0.0000027^{ns} P^2. Coefficient regression for maximum seed weight per hectare using response surface analysis was not significantly different at a dose of SP-36 and KCl. The optimum dosage of urea 0 kg ha^{-1}, SP-36 289.03 kg ha^{-1}, KCl 87.12 kg ha^{-1} gave the maximum seed weight of 2.01 tons. ha^{-1} (Figure 2). The soybean in the intercropping system of *kayu putih* about 2 tons. ha^{-1} was a good result compared with the intercropping in fertile sites, such as East Java teak forests. The soybean yields grown in the shade of teak forest with a level of 5-10% at KPH Padangan, Bojonegoro, Banyuwangi, Jember, and Blitar could produce around 1.2 tons ha^{-1}. Meanwhile in Ngawi KPH, soybean productivity was ranged from 0.7 to 1.1 tons ha^{-1} (Kementrian Pertanian, 2012).

The use of urea to produce maximum grain weight did not influence. The cause of the ineffectiveness

Table 6. The interaction of SP-36 and KCl fertilizer on yield component

SP-36 (kg. ha^{-1})	KCl (kg. ha^{-1}) 0	KCl (kg. ha^{-1}) 75	KCl (kg. ha^{-1}) 150	Mean
Number of seeds/plants				
0	33.40 b	39.93 ab	32.96 b	35.43
150	37.33 ab	40.11 ab	46.69 a	41.38
300	44.78 a	37.44 ab	45.44 a	42.56
Mean	38.50	39.16	41.70	(+)
Seed weight/plants	....	g	....	
0	5.33 c	6.62 abc	5.18 c	5.71
150	5.89 bc	6.83 abc	7.20 ab	6.64
300	7.57 ab	6.34 abc	7.78 a	7.24
Mean	6.26	6.61	6.72	(+)
Seed weight/hectare	....	tons	....	
0	1.31 c	1.77 ab	1.33 c	1.47
150	1.54 bc	1.69 abc	1.98 ab	1.73
300	1.88 ab	1.72 abc	2.02 a	1.88
Mean	1.58	1.73	1.78	(+)

Remarks: Number followed by letter the same in the column indicated no significant difference according to DMRT at 5% levels. Sign (+) indicated there was an interaction found between the factors tested.

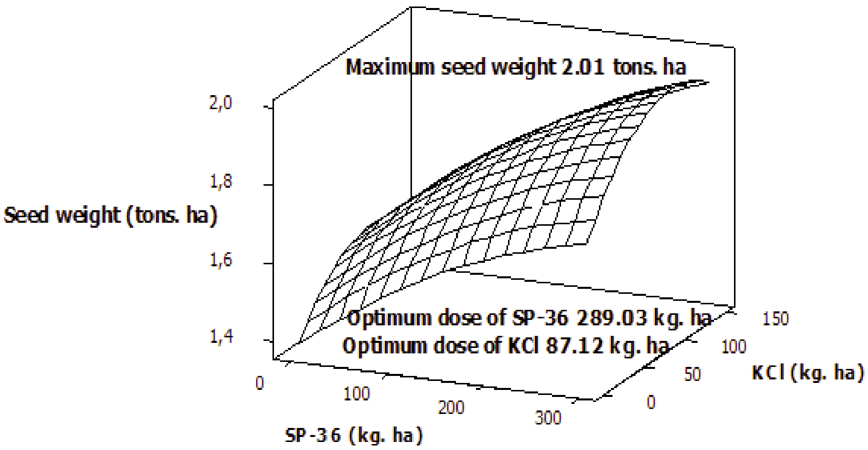

Figure 2. SP-36 and KCl treatment in the urea dose 0 kg.ha^{-1}

of using urea fertiliser to seed yield might be related to the fulfillment of fertiliser given in the vegetative stage of plant growth and development. Plants which were treated without urea could still meet the needs of N through nitrogen fixation. Observations using isotope indicated that the content of N_2 in the air was correlated with soybean root nodule formation (Schweiger *et al*., 2014). The dosage of fertiliser N required by soybean plants was lower compared with cereal crops, but soybean N uptake was greater than cereal crops. This could happen because soybean was capable of fixing N_2 from air (Sisworo *et al*., 1985).

CONCLUSION

The optimum dosage was obtained, i.e. urea 0 kg ha^{-1}, SP-36 289.03 kg ha^{-1}, and KCl 87.12 kg ha^{-1} that was able to produce a maximum seed weight amounted to 2.01 tons ha^{-1}. Fertilisation using urea 50 kg ha^{-1}, SP-36 300 kg ha^{-1}, KCl 150 kg ha^{-1} was able to increase N, P, K uptake per hectare, amounted to 16.23 kg N ha^{-1}, 86.27 kg P ha^{-1}, and 0.02 kg K ha^{-1}. The combination of urea with SP-36 and SP-36 with KCl showed interactions in leaf area, photosynthetic rate, number of seeds per plant, seed weight per plants, and seed weight per hectare.

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