Chemical Characteristics of Exchangeable Al, Fe, Mn, and Inorganic P Fraction Ultisols at Forest, Dry Land and Rice Fields Land Use in Jasinga, Indonesia

by Erlina Rahmayuni

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Erlina Rahmayuni*, Syaiful Anwar, Budi Nugroho, and Lilik T. Indriyati

***Abstract*—Different land use at the study site such as forest, dry land and rice fields originating from the same soil type, affects the presence of various phosphorus (P) fractions in the soil profile. The purpose of this study was to study the chemical characteristics of Al, Fe, Mn, exchangeable and inorganic P fractions of the soil on the Ultisol soil profile using forest, dry land and rice fields in Jasinga. Soil samples were taken on three horizons (Ao or Ap, AB and B) at profiles of forest soil and dry land, while in paddy fields taken at a depth of 0–20 cm, 20–40 cm and 40–60 cm from the ground surface. The chemical properties of the soil analyzed were soil pH, C-organic, exchangeable-Al, exchangeable-Fe, exchangeable-Mn and P fractionation. The results showed that the soil in the study site had a cleavage texture with a pH range of very acidic to slightly acidic. The highest exchangeable-Al levels were found in forest land at 433 ppm, the highest exchangeable-Fe was in rice fields at 0.019 ppm and the highest exchangeable-Mn was in dry land use at 0.063 ppm. The significant correlation of the (Ca, Mg)-P fraction with soil pH of selected chemical properties on dry land showed that this fraction would increase with increasing pH and vice versa would decrease with increasing exchangeable-Al and exchangeable-Mn.**

***Index Terms*—Correlation, combination method, land use**

I. INTRODUCTION

Ultisols are one of the most widespread acid soil orders, covering 45.8 million ha or 25% of Indonesia's land area. Ultisol distribution pattern in an area is generally based on troposequen and associated with Oxisol, Alfisol Inceptisol and Entisol [1]. One of the Ultisols in West Java is found in Jasinga District, Bogor Regency. The process of formation of Ultisols including Ultisols in Jasinga is influenced by a wet tropical climate with high rainfall every year so that there is an intensive process of weathering and washing of bases, especially in the upper horizon (eluviation) with an argillic characterizing horizon.

Ultisols develop from various acid to alkaline parent materials, but most of the Ultisol parent materials are acidic sedimentary rocks [2]. Ultisols in Indonesia are generally formed from acidic sedimentary parent materials derived from klei rock [3]. Based on the Geological Map of Serang Sheet (1991), Jasinga Subdistrict is included in the Bojong manik formation (TMb) with the parent rock constituent materials (geological formations) derived from alternating sandstone with klei, marl and limestone interspersed. formed. Ultisols formed from volcanic parent material and limestone will have a higher level of soil fertility than Ultisols formed from sedimentary rocks [2].

Ultisols are characterized by high soil acidity, low organic matter content, high exchangeable-Al, low nutrient content, especially P and low base cations (Ca, Mg, K and Na) [4]. Added by Prasetyo and Suriadikarta [2] Ultisols generally have a KB value <35% and a pH of 3.10–5.00, high Al and Mn saturation, low P, low CEC ($\leq$ 24 cmol$^{(+)}$/kg) soil, so that low natural fertility. According to Ywih *et al*. [5], acid soil constraints are generally related to the availability of P nutrients, and P fixation by metal ions such as Al, Fe, and Mn so that P nutrients are not available to plants.

Different land use with the application of different soil management systems will affect the level of soil fertility. Forest land use, dry land and rice fields are examples of different land uses with natural and intensive levels of processing. The presence of organic matter in forest land and oil palm plantations is correlated with the distribution of phosphorus (P) fraction in the soil surface layer [6]. Agricultural systems with soil management followed by the application of fertilizers will change the dynamics, the amount of relative availability and the form of P in the soil. The results of research concluded that phosphorus is an essential nutrient to maintain or increase productivity in plant ecosystems.

Phosphorus (P) is a nutrient that is needed by plants after nitrogen (N) [7]. The presence of P is very limited in the soil but is required in large quantities. P comes from mined phosphate rock, its existence will run out in the next 50–100 years because phosphate rock is a non-renewable natural resource [8], in addition to the low P content in the soil, phosphorus is fixed (bound) by Al on acid soils and by Ca on alkaline soils [3]. The problem of P deficiency is usually overcome by the application of P fertilizer. Efficient use of P is needed in relation to the transformation and behavior of various P fractions [9].

Soil P forms are generally divided into organic and inorganic forms [10]. Inorganic P (Pi) comes from primary minerals (apatite), phosphate complexes of Ca, Fe and Al and P are adsorbed in klei particles. Meanwhile, organic P (Po) comes from the remains of plants, animals and micro-organisms and is composed of nucleic acids, phospholipids and fitins [10]. Suriadi and Belakang [11]

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reported that generally the P fraction was found in soil in three fractions, namely the P-solution fraction, the P-labile fraction and the non-labile P fraction.

The P content of cultivated soil is strongly influenced by the application of P fertilizer applied to agricultural land [12]. Different land use at the study site such as forest, dry land and rice fields originating from the same soil type, namely Ultisol, is expected to affect the presence of various P in the soil. Likewise with the distribution of the presence of P in the soil profile in each soil horizon. In previous studies in intensive agricultural areas, the impact of application of P fertilizer can be detected by the accumulation of P fertilizer found in the lower horizon of the soil profile [13].

The diversity of soil chemical properties at a location is an important thing that must be considered in agricultural management, including the relationship between various land uses with the characteristics of Al, Fe, Mn exchangeable and P fraction in Ultisols. Therefore, it is necessary to conduct research to see the chemical characteristics of exchangeable Al, Fe and Mn soil which is a P-binding element. dry land and rice fields in Jasinga.

II. MATERIALS AND METHODS

The research was conducted on three types of land use, namely forest at the coordinate position of 6°30'3.321"LS–106°25'11.764"BT, dry land at 6°30'1.437"LS–106°25'10.873"BT Longitude, and rice fields at 6°30'3.164"LS–106°25'11.771"BT in Curug Village, Jasinga District, Bogor Regency, West Java. Soil analysis was carried out at the Laboratory of Chemistry and Soil Fertility, Department of Soil Science and Land Resources, Faculty of Agriculture, Bogor Agricultural University (IPB). Analysis of soil exchangeable-Al levels was carried out at the Testing Laboratory of the Indonesian Institute of Soil Research, Agricultural Research and Development. The study was conducted from August 2020 to January 2021.

The research consisted of four activities, namely: determining the point of taking soil samples, taking soil samples, analyzing soil samples and analyzing data. Determination of the sampling point of the soil is carried out based on the overlay procedure of the soil type map and land use map (Fig. 1). Soil samples were taken on the type of use of forest, dry land and rice fields. Based on the soil map in Fig. 1, forest, dry land and rice fields are included in the Typic Hapludults soil map unit. For each type of land use, three soil profiles were made with a distance between profiles of 5–10 m, the number of these profiles was replicated. From each soil profile, three disturbed soil samples were taken according to the horizon or layer. For forest land and dry land, soil samples were taken from the A/Ap, AB/B1 and B/Bt horizons, while soil samples for paddy fields were taken at a depth of 0–20 cm, 20–40 cm and 40–60 cm. Thus the number of disturbed soil samples taken was 27 soil samples consisting of three types of land use, three profiles, and three layers of soil. Analysis of soil physical and chemical properties were texture (pipette), pH (H_2O extract), C-organic (Walkley and Black), and P-total (25% HCl extract), P fractionation (a combination of Chang and Jackson, 1957 with Tiessen and Moir 1993) (Fig. 2), exchangeable-Al [13], exchangeable-Fe and exchangeable-Mn [14, 15]. Soil chemical data obtained were then analyzed descriptively in the form of tables and graphs, and the P fractions were correlated with the selected soil chemical properties with Pearson correlation using SPSS 22.

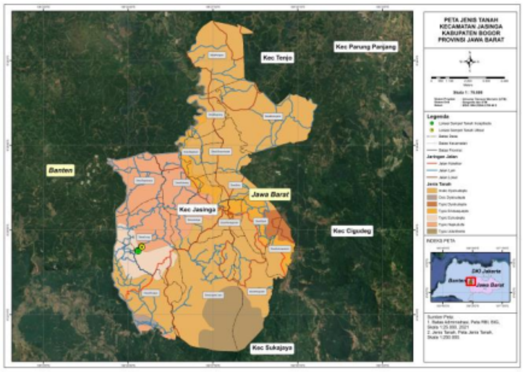


Fig. 1. Location of soil sampling in Curug Village, Jasinga.

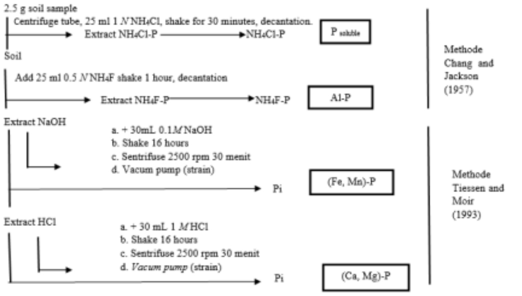


Fig. 2. P fractionation procedure combination method (Chang and Jackson, 1957 with Tiessen and Moir, 1993).

III. RESULTS AND DISCUSSION

A. *Soil Texture and Soil Chemical Character*

The results of the analysis of soil texture at the study site are presented in Table I. General soil texture at all soil depths in forest land use, dry land and klei textured rice fields. In forest and dry land there is an accumulation of klei content in the B horizon, in contrast to rice fields where the highest klei content is in the topsoil. This is thought to be due to the cultivation of paddy fields. The distribution of klei content in forest and dry land increased with soil depth, and rice fields varied with soil depth. The results of the soil texture analysis showed that there was a high content of klei in all research locations. According to Sulieman *et al*. [16] that the formation of klei accumulation in the B horizon is called the argillic characterizing horizon in the order Ultisol. Ultisol is characterized by the distribution of particles in the B horizon dominated by the klei fraction with a drastic increase (accumulation) [17].

Data on soil pH values in general on forest land, dry land and rice fields at all points of the soil profile ranged from 3.61 to 5.89, classified as very sour-slightly sour. The low pH value of the soil can be attributed to the high rainfall in the study area, which is 3.000–4.000 mm $year^{-1}$. Jasinga District has a rainfall of 3061 mm $year^{-1}$. High rainfall at the study site resulted in leaching of basic cations replaced by H$^+$ and Al^{3+}, resulting in more H ions in the soil solution and a decrease in pH [17]. In general, C-organic content in the study area was low and decreased with the depth of the soil profile in all land uses. Forest land and dry land have higher organic C content than paddy fields. The difference in the type and amount of vegetation that grows will affect the levels of C-organic (organic matter) in the use of yard land and farming land [17].

TABLE I: SOIL TEXTURE AND CHEMICAL PROPERTIES OF FOREST, DRY LAND AND PADDY FIELDS

Land	Hor./Land Dept	Sand	Dust	Clay	Texture Class	pH	C-org.	Exch-Al	Exch-Fe	Exch-Mn
		...(%)...				..(%)...			..(ppm)...	
Forest 1	A0	6.2	28.2	65.7	*Klei*	5.1	0.5	193	0.02	0.03
	AB	11.8	38.1	50.2	*Klei*	5.3	0.2	175	0.02	0.03
	B	3.6	19.4	77.1	*Klei*	5.0	0.2	82	0.02	0.03
Forest 2	A0	6.2	29.0	64.8	*Klei*	4.1	2.0	352	0.02	0.02
	AB	11.0	38.3	50.8	*Klei*	4.3	0.2	223	0.02	0.04
	B	3.6	20.2	76.2	*Klei*	4,7	0.6	215	0.02	0.04
Forest 3	A0	6.1	29.0	64.9	*Klei*	4.0	1.8	423	0.02	0..03
	AB	11.8	38.0	50.3	*Klei*	4.0	0.4	317	0.02	0.03
	B	3.9	20.1	76.0	*Klei*	4.4	0.4	422	0.02	0.04
Dry land 1	A0	5.1	23.2	71.7	*Klei*	3.7	1.0	317	0.02	0.06
	AB	5.5	23.7	70.8	*Klei*	3.7	0.4	329	0.02	0.06
	B	8.5	29.8	61.8	*Klei*	3.8	0.5	404	0.02	0.06
Dry land 2	A0	5.1	24.0	70.9	*Klei*	3.7	1.7	37	0.0	0.03
	AB	5.1	24.2	70.7	*Klei*	3.8	1.3	45	0.01	0.04
	B	5.3	30.1	71.1	*Klei*	3.9	0.6	37	0.02	0.06
Dry land 3	A0	5.1	23.6	71.3	*Klei*	3.7	1.0	40	0.02	0.03
	AB	4.5	23.8	71.7	*Klei*	3.6	0.7	24	0.02	0.03
	B	5.5	19.9	74.66	*Klei*	3.9	0.5	41	0.02	0.05
Paddy field 1	0–20	4.7	24.5	70.8	*Klei*	5.5	0.9	31	0.01	0.02
	20–40	6.1	27.2	66.7	*Klei*	5.5	0.6	12	0.02	0.01
	40–60	5.2	27.0	67.8	*Klei*	5.5	1.0	12	0.01	0.01
Paddy field 2	0–20	4.7	24.5	70.8	*Klei*	5.5	0.7	41	0.02	0.03
	20–40	6.0	26.8	67.2	*Klei*	5.5	0.7	35	0.02	0.01
	40–60	5.2	26.9	67.8	*Klei*	5.9	0.6	34	0.02	0.01
Paddy field 3	0–20	4.7	24.5	70.8	*Klei*	5.3	0.8	32	0.01	0.03
	20–40	6.2	27.2	66.1	*Klei*	5.3	0.7	41	0.02	0.01
	40–60	5.3	27.0	67.7	*Klei*	5.9	0.6	39	0.02	0.01

The highest exchangeable-Al levels were found in dry land at 404 ppm, rice fields at 41 ppm and forests at 23 ppm. The difference in exchangeable-Al levels is in stark contrast between the use of dry land with forest and rice fields. Exchangeable-Fe levels at all study sites were generally the same, namely in the range of 0.01-0.02 ppm, with distribution varying with soil depth. The highest levels of exchangeable-Mn were generally in dry land (0.06 ppm), forest (0.04 ppm) and rice fields (0.03 ppm) with distribution varying with soil depth. The results of previous studies located in Jasinga showed different results, Arifin *et al*. [17] obtained exchangeable-Al levels of 1800–2200 ppm, exchangeable-Fe of 35.05 ppm and exchangeable-Mn of 212.09 ppm and reported levels of exchangeable-Fe 1.59 mg Kg^{-1} and Mn-dd 21.73 mg Kg^{-1}. The levels of exchangeable-Al, exchangeable-Fe and exchangeable-Mn at the study site were very low when compared to previous studies which indicated that there were differences in chemical properties that differed from the soil characteristics in all land uses at the study site.

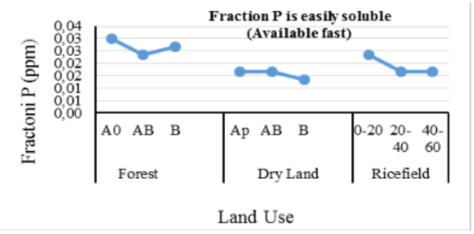
B. Inorganic P Fraction on Forest, Dry Land and Rice Field Use

The concentration of the inorganic P fraction on the use of forest, dry land and paddy fields is shown in Fig. 3. The distribution of the concentration and percentage of inorganic P in the use of forest, dry land and rice fields is described in Table II. In Table II the concentration data of the P fraction which is normal data (ppm) compared to the relative data of the P fraction (%). Soil P grouping in this study was based on several fractions, namely the soluble P fraction (NH_4Cl extract) which is a form of rapidly available fraction, the Al-P fraction (NH_4F extract), the (Fe, Mn)-P fraction (NaOH extract) and the (Ca, Mg)-P fraction (HCl extract) is the form of the slow fraction available. The number of Al-P and (Fe, Mn)-P fractions in Table II, characterizes very acidic soils, while the (Ca, Mg)-P fractions characterize slightly alkaline to alkaline soils. Residual-P fraction was obtained from the reduction of P extracted by HCl 25% with the amount of available fast P and slow P fractions available.

TABLE II: DISTRIBUTION OF CONCENTRATIONS AND PERCENTAGES OF INORGANIC P IN THE PROFILE OF FOREST USE, DRY LAND AND PADDY FIELDS

Land	Hor./Land Depth (cm)	P Available Quick		P Slow Available				Residual P		P-Total/ P potential (HCl 25%)	
		P easily available		Al-P, dan (Fe, Mn)-P		(Ca, Mg)-P		(P not available)			
		ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
Forest 1	A0	0.03	0.02	0.08	0.06	0.10	0.08	122.89	99.84	123.09	100
	AB	0.01	0.01	0.07	0.05	0.07	0.05	152.95	99.94	153.04	100
	B	0.02	0.01	0.03	0.02	0.04	0.02	165.01	99.96	165.07	100
Forest 2	A0	0.01	0.01	0.06	0.03	0.02	0.01	201.18	99.96	201.27	100
	AB	0.01	0.01	0.06	0.04	0.01	0.01	164.00	99.95	164.08	100
	B	0.01	0.01	0.05	0.03	0.01	0.01	153.94	99.96	154.00	100
Forest 3	A0	0.01	0.01	0.05	0.03	0.07	0.04	179.32	99.93	179,45	100
	AB	0.01	0.01	0.06	0.04	0.06	0.04	165.46	99.94	165,56	100
	B	0.01	0.01	0.06	0.04	0.06	0.04	150.91	99.95	150,98	100
Dra Land 1	Ap	0.01	0.01	0.07	0.03	0.02	0.01	210.00	99,96	210.08	100
	B1	0.02	0.01	0.06	0.04	0.02	0.01	162.26	99,95	162.34	100
	B2	0.01	0.01	0.05	0.03	0.02	0.01	156,71	99,96	156.78	100
Dry Land 2	Ap	0.01	0.01	0.05	0.03	0.03	0.02	175.95	99.95	176.03	100
	AB	0.01	0.01	0.06	0.04	0.03	0.02	166.98	99.94	167.08	100
	B	0.01	0.01	0.04	0.03	0.02	0.01	145.03	99.96	145.09	100
Dry Land 3	Ap	0.02	0.01	0.04	0.02	0.04	0.02	175.03	99.95	175.12	100
	AB	0.01	0.01	0.04	0.02	0.03	0.02	163.14	99.94	163.23	100
	B	0.01	0.01	0.04	0.04	0.02	0.02	101.14	99.93	101.21	100
Ricefield 1	0 - 20	0.01	0.01	0.05	0.03	0.06	0.04	159.91	99.94	160.01	100
	20 - 40	0.02	0.01	0.05	0.03	0.06	0.04	168.23	99.95	168.32	100
	40 - 60	0.01	0.01	0.02	0.01	0.05	0.04	138.98	99.96	139.03	100
Ricefield 2	0 - 20	0.01	0.01	0.04	0.02	0,07	0.04	163,97	99,94	164.07	100
	20 - 40	0.01	0.01	0.05	0.04	0.06	0.04	137,79	99,91	137.91	100
	40 - 60	0.01	0.01	0.05	0.03	0.05	0.03	160,99	99,94	161.08	100
Ricefield 3	0 - 20	0.02	0.01	0.05	0.03	0.06	0.03	173.96	99.94	174.06	100
	20 - 40	0.02	0.01	0.06	0.03	0.06	0.03	187.94	99.95	188.03	100
	40 - 60	0.02	0.02	0.04	0.04	0.07	0.07	101.02	99.93	101.09	100

Fig. 3 shows that the dominant soil P fraction is the (Ca, Mg)-P fraction, which is found in forest and paddy fields. The general difference between land uses in the study area showed that forest land, had a higher fraction of fast available and slow available [18] stated that natural land had more Pi accumulation on the soil surface (Ah) compared to conventionally cultivated land. The general trend of distribution of soluble P, Al-P, and (Fe, Mn)-P fractions of soil in all land uses varies with soil depth. The distribution pattern of the Fe fraction varies with the depth of the soil in various cropping systems. Meanwhile, the distribution pattern of the (Ca, Mg)-P fraction decreased with soil depth in all land uses. In accordance with the research of Anwar *et al*. [19], there was a decrease in the concentration of the (Ca, Mg)-P fraction with soil depth on forest and agroforestry land.



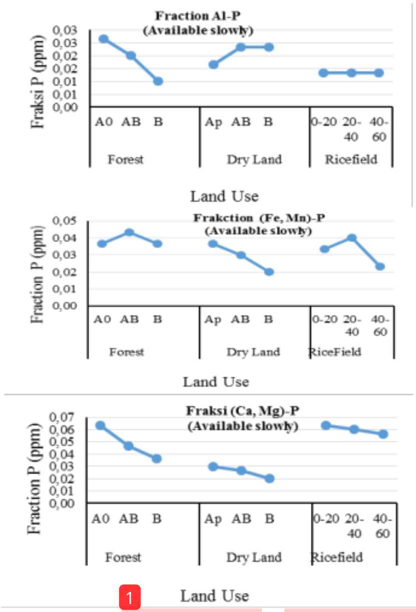


Fig. 3. Concentration of inorganic P fraction in forest, dry land and paddy field use profiles.

Based on the data from Table II, in general the percentage of the rapidly available P fraction in soil is very low compared to the late available P fraction and the P-residual fraction in all land uses. Fraction (Ca, Mg)-P > Al-P, (Fe, Mn)-P > P is soluble in forest use 1 and forest 3 as well as in all paddy fields. Residual-P fraction was generally high in all land uses (99.96%) indicating that only a small fraction of P in the fast form was available (0.01–0.02%), the late P fraction was available from the Al-P fraction and (Fe, Mn)-P fraction (0.01–0.06%) and (Ca, Mg)-P fraction (0.01–0.08%). According to Anwar *et al*. [19] that most of the P in the form of unavailable (93.4–94.5%), slowly available (3.6–4.2%) and quickly available (1.9–2.6%) sequence for plants.

C. Relationship of Inorganic P Fraction with Chemical Properties of Selected Soil

The results of the correlation between the inorganic P fraction and the chemical properties of selected soils in forest, dry land and paddy fields are presented in Table III. In dry land, the (Ca, Mg)-P fraction is significantly negatively correlated with exchangeable-Al and exchangeable-Mn and significantly positive correlation with pH. The significant correlation of the (Ca, Mg)-P fraction with selected chemical properties on dry land showed that this fraction would increase with increasing pH and vice versa would decrease with increasing exchangeable -Al and exchangeable-Mn. The availability of P is strongly influenced by soil pH, the amount of Al, Fe and Mn and minerals containing these three elements, the availability of Ca, the amount and decomposition of organic matter and the activity of microorganisms [19]. This significant correlation seems to be due to the synergistic or antagonistic relationship between the P fractions and the chemical properties of the soil.

TABLE III: PEARSON CORRELATION OF FRACTION P WITH SELECTED SOIL CHEMICAL PROPERTIES ON THE PROFILE OF FOREST LAND, DRY LAND AND RICE FIELDS

Land	P fraction	pH	Exch-Al	Exch-Fe	Exch-Mn
Forest	$P_{soluble}$	0.39	0.18	0.18	0.14
	Al-P	0.23	0.38	0.1	−0.52
	(Fe, Mn)-P	−0.4	0.17	−0.33	0.57
	(Ca, Mg)-P	0.18	0.14	−0.4	−0.13
Dry Land	P_{solube}	0.59	−0.37	0.06	0.11
	Al-P	−0.26	0.17	−0.28	0.6
	(Fe, Mn)-P	0.22	−0.43	0.48	−0,03
	(Ca, Mg)-P	**0.75***	**−0.81****	0.45	**−0.75****
Ricefield	P_{solube}	0.35	−0.13	−0.57	0.41
	Al-P	−0.16	0.33	0,16	−0.12
	(Fe, Mn)-P	−0.12	0.38	0.46	0.02
	(Ca, Mg)-P	0.01	0.54	0.54	0.49

* Very real ($p<0.01$)
** real (value $p<0.05$)

IV. CONCLUSION

Chemical characteristics of Ultisol Jasinga include low exchangeable-Fe and exchangeable-Mn, dominant in rice fields, followed by forests, and lowest in dry land. The significant correlation of the (Ca, Mg)-P fraction with soil pH of selected chemical properties on dry land showed that this fraction would increase with increasing pH and vice versa would decrease with increasing exchangeable-Al and exchangeable-Mn.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Erlina Rahmayuni designed the research plan, participated in all experiments an contributed to the writing of the manuscript. Syaiful Anwar verifed the analytical methods, analyzed the data. Budi Nugroho carried out the experiments. Lilik Tri Indriyati coordinated the mouse work. All authors had approved the final version.

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