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CHARACTERIZING THE SOIL FOR IMPROVED NUTRIENT MANAGEMENT IN SELECTED MAIZE GROWING AREAS OF INDONESIA

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ABSTRACT

The demand for maize, the second most important food crop in Indonesia, is steadily increasing. Knowledge of soil properties is a key element in developing nutrient management system. The aims of this study were to characterize and classify the soils at the family level of Soil Taxonomy and linking the taxa with nutrient management systems. The study was conducted at the Site Specific Nutrient Management (SSNM) for maize in Indonesia from June to October 2005. Eight soil profiles were taken from Karo (North Sumatra), Sidomulyo (Lampung), Wonogiri and Grobogan (Central Java), Wonokerto, Mojoayu, and Tuban (East Java), and Jeneponto (South Sulawesi). The soil samples were analyzed for their physical, chemical, and mineralogical characteristics. Soil profile description followed the Standard Guidelines of the Food and Agriculture Organization. Results showed that the sites for the SSNM represented a wide range of soils and climate characteristics from Entisols with 1,050 mm annual rainfall in Jeneponto to Oxisols with 2,200 mm annual rainfall in Lampung. Most soils had a fine texture class (clay and clay loam), but in places like Lampung and Wonogiri, the clay had a low activity leading to a low cation exchange capacity (CEC) and low exchangeable cations, especially K. The relatively high-K status soils were found in Karo, Grobogan, and Tuban sites. Organic matter and, in consequence, total N were relatively low for all SSNM sites. Available P status ranged from low to high. The low available P in Grobogan, Wonokerto, and Mojoayu soils seemed to be related to high pH, while in Lampung it was due to low pH. Exchangeable Ca and Mg were high in Grobogan, Mojoayu, Karo, and Tuban due to the presence of weatherable minerals such as hypersthene, augite, and hornblende. In general, this study suggests that organic matter, N, and P will be needed across the sites. K addition will be necessary for Karo, Lampung and Wonogiri, while in other SSNM areas, maintenance rates for K will be needed unless plant residues are recycled.

[***Keywords***: Soil characteristics, classification, nutrient management, fertilizer recommendations, maize]

INTRODUCTION

Maize production in Indonesia has dramatically increased from 9.7 million t in 2000 to 17.8 million t in 2010, while the yield has increased from 2.8 to 4.3 t ha^{-1} in the respective time scale (BPS 2011; Ministry of Agriculture 2011). However, until 2010 Indonesia still imported around one million ton of maize. The soil and climate of Indonesia is capable of supporting a much higher yield to more than 6 t ha^{-1} and this could be achieved among others, by improved nutrient management. In the dryland of China, maize yield ranged from 3 to 10 t ha^{-1} depending on the management of nutrient, organic matter, and water (Wang *et al*. 2010).

North Sumatra, Lampung, Central Java, East Java, and South Sulawesi make up a large part of maize production areas of Indonesia. These areas differ in physical environments and soil characteristics and hence influence maize productivity. To support the nutrient management in particular and soil management in general, information on soil characteristics and its environmental conditions become very important.

Key physical environments and soil characteristics should be considered to determine soil and fertilizer management strategies. In general, maize can grow optimally in areas with mean temperature between 18°C and 32°C and annual precipitation between 500 and 5,000 mm. The optimal annual rainfall is 1,000-1,500 mm, 500-1,200 mm of which should be within in the growing period under rainfed condition. Maize can grow on many types of soils. Well drained, well aerated, deep loam, and silt loam soils with adequate organic matter are most suited for maize cropping. On soils with a low moisture retention capacity, or in areas of low rainfall, a low plant density should be used. Maize yield increases with planting density on irrigated plot, but the reverse may occur on rainfed plots. Soil fertility characteristics which are suitable for maize, have a range of pH 5.8-7.8, apparent cation exchange capacity (CEC) > 16 cmol(+) kg^{-1} clay, base saturation > 20%, sum of basic cations > 2 cmol(+) kg^{-1} soil, and organic carbon >0.5% (Sys *et al.* 1993; Djaenudin *et al*. 2003).

Although there are large areas suitable for maize growing in Indonesia, based on their intrinsic soil and climate conditions, the management level is a key to increase productivity of these potential areas, especially under intensive systems. Adjusting the management level with the soil characteristics is therefore the key to farming efficiency and sustainability.

Soil characteristic data are crucial in guiding nutrient management and in determining nutrient recommendation domain. In an effort to improve maize production, the Indonesian Agency for Agricultural Research and Development (IAARD) in collaboration with the Potash and Phosphate Institute (PPI) was conducting research on Site Specific Nutrient Management (SSNM) for maize. In this endeavour, characterization of soils is an important element in determining fertilizer recommendation domains.

This research is part of a larger framework of the SSNM project in Asia (Dobermann *et al*. 2002). The commodities covered by the project were rice and maize. The overall goal of the project was to improve nutrient management for maize in key production areas for higher crop yield and production sustainability. This is in line with Indonesian target of maize self-sufficiency by 2010 as outlined in the Agriculture, Fisheries, and Forestry Revitalization strategy launched in 2005.

This study aimed at characterizing the soils at the SSNM research sites and relating the characteristics with nutrient management for leveraging maize yield.

MATERIALS AND METHODS

Eight soil profiles were chosen in the vicinity of the SSNM research sites in five provinces as shown in Table 1. The sites were chosen based on the major distribution of maize planting area in Indonesia. Physical environment of all the sites, such as location, topography, parent material, and soil had been studied from available research reports before the fieldwork was conducted. During the fieldwork, that was conducted in 2005, soils at the research sites were intensively observed using the techniques of augering, mini-pit, and soil profile.

Soil augering was done up to 120 cm depth. Observation by mini-pit was done from 50 cm deep pit and then continued by augering to 170 cm depth. A representative soil pit (profile) of 150-200 cm depth was made at each experimental site. Morphological characteristics of soil profiles were described using the Standard Guidelines for Soil Profile Description (FAO 1990; Soil Survey Division Staff 1993) and classified according to Soil Taxonomy System (Soil Survey Staff 2003).

Each soil profile (consisted of 5-7 horizons) was observed and sampled for the determination of color, texture, structure, rock fragments, and the chemical, physical, and mineralogical properties required for classifying the soil at family level of the Soil Taxonomy System. Undisturbed ring samples at 0-20 cm and 20-40 cm depth were taken to determine soil bulk density.

The analyses of chemical characteristics consisted of particle size, pH (H_2O and KCl), organic C, total N, potential P_2O_5 and K_2O (25% HCl extraction), available P_2O_5 (Olsen or Bray-l extractions), P retention, exchangeable cations, CEC (1N NH_4-OAc, pH 7.0), and exchangeable acidity (Al and H, with 1 M KCl). Physical characteristics included bulk density, total pores, drainage pores, available water, and permeability. Mineralogical analyses were conducted by microscopic method for the sand fraction to determine the soil parent material and reserved minerals. The procedure for the analyses followed the standard methods described in the Soil Survey Laboratory Methods Manual (Soil Survey Laboratory Staff 1992). Mineralogical types of the clay fraction were determined by X-Ray Diffraction instrument to distinguish families of the soils in Soil Taxonomy.

All the soil characteristic data were processed and interpreted according to the Soil Taxonomy to deter-

Table 1. Soil profile observation sites of the Site Specific Nutrient Management (SSNM) for Maize in Indonesia.

Profile code	Altitude, coordinate	Site, district	Province
AF1	730 m asl, 98°23' E and 99°48' S	Simpang Perbesi, Karo	North Sumatra
AF2	116 m asl, 105°06' E and 5°15' S	Sidomulyo, Lampung	Lampung
KM1	120 m asl, 110°59' E and 7°45' S	Ngadirejo Kidul, Wonogiri	Central Java
KM2	43 m asl, 110°50' E and 7°23' S	Krangganhardjo, Grobogan	Central Java
KM3	158 m asl, 112°12'30" E and 7°35'25" S	Wonokerto, Kediri	East Java
KM4	160 m asl, 112°12'35" E and 7°35'27" S	Mojoayu, Kediri	East Java
KN2	10 m asl, 112°04"50' E and 6°57"08' S	Prunggahan, Tuban	East Java
KN1	10 m asl, 119°48"10' E and 5°41"12' S	Tolo Utara, Jeneponto	South Sulawesi

mine their soil families (Soil Survey Staff 2003). Soil properties that may affect maize growth were evaluated and possible nutrient management options for each site of the SSNM for maize were assessed.

RESULTS AND DISCUSSION

Soil Characteristics at SSNM Experimental Site in North Sumatra (AF1)

The SSNM experimental site for maize was located at Tiga Binanga Subdistrict, about 35 km west of Kabanjahe, Karo District, North Sumatra. A representative soil profile AF1 was taken at the first plot of maize in Simpang Perbesi Village with a geographic position of 98°23' East and 99°48' South. The studied area, according to climatic data of Seribu Dolok Station, had an annual rainfall of 1,904 mm and a mean air temperature of 21.7°C. In the agro-climatic map of Sumatra (Oldeman *et al.* 1979), this area belongs to the D2 zone consisting of 3-4 wet months and 2-3 dry months. Soil temperature and moisture regimes according to Soil Taxonomy (Soil Survey Staff 2003) were classified as *Isohyperthermic* and *Udic,* respectively.

Soil in the research site developed on undulating (1-3%) landform of Quaternary Toba Acid Tuff at the elevation of 730 m above sea level (asl). The soil profile AF1 had a horizon sequence of Ap - Bw1 - Bw2 - Bw3 - Bw4 - BC - C. All the soil horizons were characterized by homogeneous dark greyish-brown (10YR4/4) color, clay loam texture, sub-angular blocky structure, and gradual horizon boundaries. The bottom horizons, BC and C, had a light bright-grey (10YR6/2) color and sandy loam texture. The darker color and very friable consistency in the thin surface horizon (Ap) may relate to the high organic matter content. The homogenous color, texture, and consistency of the Bw horizons indicated that the soil developed in a well-drained condition. The coarser texture and lighter color at the bottom horizons (BC and C) were related to the parent material properties.

The texture was clay loam to sandy clay loam. The soil had a neutral reaction (pH H_2O: 6.6-7.6), low in organic-C (0.15-1.41%) and total N (0.02-0.11%), slightly low CEC (10.6-16.4 cmol(+) kg^{-1}), and high base saturation (>90%) with dominant Ca and Mg cations. The relative low values of NH_4OAc extractable CEC could be related to crystalline minerals, such as halloysite and illite. The high potential P_2O_5 (320-620 mg kg^{-1}) and K_2O (990-2,450 mg kg^{-1} K_2O), and high available P_2O_5 (34-63 mg kg^{-1}) and exchangeable K (2.1 cmol(+) kg^{-1}) may be related to the soil's high weatherable mineral content, such as hornblende, glass, augite, hypersthene, sanidine, and biotite. These minerals indicate good indigenous nutrient supply, especially for Ca, Mg, and K. The bulk density was moderate (1.05-1.15 g cm^{-3}) and the soil had lots of fast drainage pores (18.4-22.4%), and rapid to medium permeability (4.32-7.94 cm $hour^{-1}$) indicating porous structure which is good for rooting environment. The chemical, physical, and mineralogical characteristics of this soil are presented in Table 2.

According to the Keys to Soil Taxonomy (Soil Survey Staff 2003), the thin surface horizon (Ap) meets the requirements for an ochric epipedon and the sub-subsurface horizons (Bw1-4) fulfil the requirements for a cambic diagnostic horizon. The relatively high bulk density (>0.9 g cm^{-3}), low P retention (13.7-30.7%), and slightly high Al plus 1/2 Fe oxalate (1.1-2.1%) are reflections of weak andic properties. The amorphic mineral content of this soil is shown by the sum of 8 times the Si plus 2 times the Fe that is more than 5. Therefore, the soil is classified as belonging to the *Andic Eutrodept* subgroup and to the *fine, amorphic, isohyperthermic Andic Eutrudept* family level (Soil Survey Staff 2003).

In general, the physical, chemical and mineralogical properties of this soil are favorable for root development. The soil consists of high weatherable minerals, high in available P_2O_5, high exchangeable Ca, Mg and K, but low in organic C and total N. These characteristics are implying that for satisfactory maize yield it needs high amount of N fertilizer and organic matter (Abdurachman and Agus 2001; Cooperland 2002). Moderate to maintenance rates of P and K fertilizers will be needed. K application may be exempted if plant residues are recycled.

Soil Characteristics at SSNM Experimental Site in Lampung (AF2)

The site in Lampung was located in Sidomulyo Village at a geographic position of 105°06' East and 5°15' South. Climatic condition of this location was based on Tegineneng (69 m asl) and Metro (57 m asl) stations, with the annual rainfall of 2,497 and 2,205 mm, respectively. Air temperature data from Tanjung Karang station ranged between 24.7°C and 26.0°C. The climate zone belongs to C1 (Oldeman *et al.* 1979). Soil moisture and temperature regimes in the studied soil according to Soil Taxonomy (Soil Survey Staff 2003) can be classified as *Udic* and *Isohyperthermic* regimes.

Table 2. Chemical and physical soil characteristics and sand mineral of the profile AF1 at Karo site, North Sumatra.

Property and unit	Soil horizon				
	Ap	Bw1	Bw2	Bw3	Bw4
Depth (cm)	0-16	16-40	40-70	70-96	96-130
Texture class	CL	C	CL	CL	C
pH (H_2O)	7.60	6.90	6.80	6.80	6.60
Organic-C (%)	1.41	0.48	0.39	0.31	0.15
Organic-N (%)	0.11	0.05	0.04	0.03	0.02
HCl 25% extractable					
P_2O_5 (mg kg^{-1})	580	580	620	620	320
K_2O (mg kg^{-1})	2,320	1,110	990	1,580	2,450
Olsen P_2O_5 (mg kg^{-1})	63	38	40	51	34
Exchangeable cation (cmol(+) kg^{-1})					
Ca	16.50	9.90	10.40	8.60	6.60
Mg	10.00	3.50	3.90	4.00	3.20
K	2.10	0.90	0.60	1.80	2.20
Na	0.10	0.10	0.50	0.30	0.20
Sum	28.70	14.40	15.40	14.70	12.20
CEC pH 7	16.40	16.00	14.20	13.60	10.60
Base saturation (%)	100.00	90.00	100.00	100.00	100.00
P retention (%)	18.50	30.70	28.70	25.30	13.70
Oxalate Al+1/2 Fe (%)	1.70	2.10	2.10	1.90	1.10
Bulk density (g cm^{-3})	1.15	1.05	Nd	Nd	Nd
Total pores (% vol.)	56.70	60.30	Nd	Nd	Nd
Fast drainage pores (%)	22.40	18.40	Nd	Nd	Nd
Slow drainage pores (%)	4.10	4.60	Nd	Nd	Nd
Available water capacity (% vol)	8.00	9.50	Nd	Nd	Nd
Permeability (cm $hour^{-1}$)	7.94	4.32	Nd	Nd	Nd
Sand fraction (50-200 mm) mineral (%)					
Opaque	44	48	40	65	24
Zircone	Sp	Sp	Sp	1	Sp
Quartz	8	4	9	6	17
Limonate	Sp	Sp	Sp	Sp	Sp
Mineral fraction	Sp	Sp	1	1	2
Rock fragments	9	11	6	6	10
Volcanic glass	-	Sp	Sp	Sp	Sp
Plagioclase	1	Sp	1	Sp	2
Feldspar	2	2	4	1	2
Mica	1	1	1	1	4
Hornblende	27	25	29	15	37
Augite	3	3	2	Sp	Sp
Hypersthene	5	6	7	4	2
Total	100	100	100	100	100
Crystalline clay minerals (<2 mm)	Ha > Il > Cr = Qz		Il > Ha > Qz > Cr		

Texture: C = clay; CL = clay loam.
Minerals: Qz = quartz; Am = amorph; Ha = haloysite; Il = illite; Cr = crystobalite.
Sp = <1%; Nd = not determined.

The soil was developed from Pre-Tertiary Rocks covered by younger andesitic volcanic material. The soil profile was taken on undulating paneplain at the elevation of 115 m asl. It had a very deep solum with good drainage. The surface horizon was reddish grey color, clay texture, and very friable consistency. The sub-surface horizons were characterized by homogenous yellowish red (2.5YR4/6) color, clayey texture, sub-angular blocky structure, friable consistency, and gradual to diffuse horizon boundaries. Soil morphology featured highly weathered soils with oxic horizons, and so the horizon sequence was Ap - Bo_1 - Bo_2 - Bo_3 - Bo_4 - Bo_5 - Bo_6.

Chemical analysis data of the soils (Table 3) show very high (68-94%) clay contents with little differences across soil depth, acid to non-acid reaction (pH H_2O: 4.8-5.8), very low organic C (0.33-1.68%) and total N (0.04-0.13%). The sub-surface horizons were

Table 3. Chemical and physical soil characteristics and sand mineral of the profile AF2 at Sidomulyo, Lampung.

Property and unit	Soil horizon				
	Ap	Bo1	Bo2	Bo3	Bo4
Depth (cm)	0-10	10-35	35-64	64-95	95-130
Clay (%)	68	92	90	89	94
pH (H_2O)	5.30	5.80	5.70	5.30	4.80
Organic-C (%)	1.68	0.77	0.47	0.43	0.33
Organic-N (%)	0.13	0.08	0.06	0.05	0.04
HCl 25% extractable					
P_2O_5 (mg kg^{-1})	380	120	120	140	130
K_2O (mg kg^{-1})	120	40	20	20	30
Olsen P_2O_5 (mg kg^{-1})	28	15	12	14	11
Exchangeable cation (cmol(+) kg^{-1})					
Ca	6.10	4.70	4.10	3.00	0.40
Mg	1.50	0.80	0.90	0.50	0.20
K	0.20	0.10	0.10	0.10	0.00
Na	0.20	0.00	0.10	0.10	0.00
Sum	8.00	5.60	5.10	3.70	0.60
CEC pH 7	5.80	2.80	2.50	2.10	1.90
Effective CEC (cmol(+) kg^{-1})	11.80	6.10	5.70	4.10	1.90
Base saturation (%)	100.00	90.00	100.00	100.00	100.00
P retention (%)	9.80	10.00	15.80	14.10	Nd
Oxide Fe (%)	4.40	5.20	5.20	5.60	5.40
Bulk density (g cm^{-3})	1.08	1.10	Nd	Nd	Nd
Total pores (% vol.)	59.10	58.60	Nd	Nd	Nd
Available water capacity (% vol.)	7.60	9.20	Nd	Nd	Nd
Permeability (cm hr^{-1})	7.88	7.04	Nd	Nd	Nd
Sand fraction (50-200 mm) mineral (%)					
Opaque	29	34	26	27	19
Zircone	Sp	Sp	Sp	Sp	Sp
Quartz	58	62	72	71	79
Iron concretion	-	1	Sp	Sp	Sp
Mineral fraction	Sp	2	Sp	1	1
Rock fragments	2	1	2	1	1
Volcanic glass	3	Sp	-	-	-
Plagioclase	4	Sp	-	-	Sp
Feldspar	Sp	Sp	Sp	Sp	-
Mica	-	-	Sp	-	-
Hornblende	2	Sp	-	-	-
Augite	2	-	Sp	Sp	-
Hypersthene	5	6	7	4	2
Total	100	100	100	100	100
Crystalline clay minerals (<2 mm)	Ka >>> Go = Qz > Io		Ka >>> Go = Qz > Io		

Minerals: Qz = quartz; Ka = kaolinite; Go = goethite; Io = iron oxide
Sp = <1%; Nd = not determined.

characterized by low potential P_2O_5 (120-140 mg kg^{-1}), very low potential K (20-40 mg kg^{-1}), very low CEC (1.9-2.8 cmol(+) kg^{-1}), apparent CEC pH 7 (2.1-3.0 cmol(+) kg^{-1} clay), and effective CEC (1.9-6.1 cmol(+) kg^{-1} clay). The sub-surface horizon was characterized by very little weatherable mineral and it met the requirements of an oxic horizon. Physical characteristics, such as low available water pores (9.2%) and slightly high permeability (7.04 cm $hour^{-1}$) were related to the formation of porous and stable structure as commonly found in oxic horizons. The surface horizon was very thin and met the requirements for an ochric epipedon. The slightly higher weatherable mineral content (volcanic glass, plagioclase, augite, and hypersthene) and sand fractions in the surface horizon could be derived from recent volcanic ash deposit.

Soils with an ochric epipedon and an oxic subsurface horizon were classified as *Oxisols* in the Soil Taxonomy Classification (Soil Survey Staff 2003). The soil climate and other characteristics of this soil met the requirements for a *Typic Hapludox* (subgroup), while at the family level the soil could be classified as *very-fine, kaolinitic, isohyperthermic Typic Hapludox.*

In general, the soil physical characteristics are favorable for root environments, but the soil has very low weatherable minerals and is poor in indigenous fertility. The low CEC and the low organic-C, total N, available P_2O_5 and exchangeable K imply that the soil needs high inputs of N, P, and K fertilizers as well as organic matter to produce satisfactory maize yields.

Soil Characteristics at SSNM Experimental Site in Central Java

The first site (profile KM1) was situated in dry farming area of Ngadirejo Kidul Village, 15 km east of Wonogori and located at 110°59' East and 7°45' South. The second site (profile KM2) was in the rice field of Krangganhardjo, about 20 km south of Purwodadi, the capital city of Grobogan District and located at 110°50' East and 7°23' South.

Climate in Wonogiri and Grobogan areas were characterized by mean annual rainfall of 2,020 mm and 2,076 mm, respectively, while air temperature, based on data from Semarang (for Grobogan) and Surakarta (for Wonogiri) ranged from 25.6 to 27.5°C and from 25.3 to 28.1°C. These sites were situated in C3 agro-climatic zone (Oldeman *et al*. 1975-1980), with five wet months (<200 mm month^{-1}) and more than three dry months (<100 mm month^{-1}). According to Soil Taxonomy (Soil Survey Staff 2003), soil moisture of these areas can be classified as *Ustic* soil moisture regime and soil temperature regime is classified as *Isohyperthermic.*

Ngadirejo Kidul, Wonogiri (KM1)

Soil profile KM1 in Ngadirejo Kidul, Wonogiri, was situated on rolling land with undulating micro-relief and slopes between 3% and 8%. Soils in this area developed from old andesitic volcanic rock which is influenced by recent volcanic ash. Morphological characteristics of the soil profile had a horizon sequence of Ap - Bt1- Bt2 - Bt3 - Bw1 - Bw2. The surface horizon (Ap) was characterized by yellowish red (5YR4/4) color, clay texture, sub-angular blocky structure, firm consistency, and acid reaction. The sub-surface horizons (Bt-Bw) showed dark reddish-brown (2.5YR3/4) to yellowish-red (5YR4/4) colors, clay texture, and sub-angular blocky structure with many clay skin and Mn concretions.

The surface horizon consisted of low organic-C (1.00%), very low total N (0.08%), very high potential P_2O_5 (620 mg kg^{-1}), medium available P_2O_5 (43 mg kg^{-1}), and low potential K (100 mg kg^{-1}). The CEC of this horizon was low (15.10 cmol(+) kg^{-1}) and dominated by Ca (6.2 cmol(+) kg^{-1}) and Mg (1.3 cmol(+) kg^{-1}) causing very high base saturation (91%). Sub-surface horizons had much higher clay content than the surface horizon, but CEC at pH 7 ranged from 9.8 to 11.0 cmol(+) kg^{-1}). Apparent CEC and effective CEC (11.4-12.6 and 12.2-12.8 cmol(+) kg^{-1}) of the sub-surface horizons were low and considered as a kandic horizon. Organic-C, total N, potential P_2O_5, and available P_2O_5 were also lower in the sub-surface horizons than in the surface horizon. Cation exchange complex was dominated by Ca and Mg causing very high base saturation. Chemical and physical data of this soil are presented in Table 4.

Morphological, chemical, physical, and mineralogical properties of the soil in Wonogiri show that the soil is a high weathering product of volcanic material forming a deep clayey soil with a kandic horizon. Under ustic moisture regime, the soil can be classified at the great group level as *Rhodic Kanhaplustalf* and at the family level as *very-fine*, *kaolinitic*, *isohyperthermic Rhodic Kanhaplustalf.*

In general, the greatest difference between the surface horizon and the sub-surface horizons is in the soil pH, P_2O_5 content, and bulk density. The surface horizon is more acidic, has a higher potential and available P_2O_5, and lower bulk density than the sub-surface horizons. In addition, the surface horizon which is important for root growth has low contents of organic-C, total N, and low CEC and exchangeable K. The available P_2O_5 of the surface horizon is also low for maize production. It is therefore, important to use organic matter and N, P, and K fertilizers in maize production on this soil. The *ustic* soil moisture regime indicates that water stress can occur and thus, mulching or supplementary irrigation system are advisable.

Krangganhardjo, Grobogan (KM2)

The SSNM site in Krangganhardjo, Grobogan, was located on alluvial land with flat relief. Soils in this area developed from alluvio-colluvium materials consisting of various sedimentary rocks, such as claystones, limestones, and shales. The materials were mixed with volcanic ash as characterized by dominant plagioclase and quartz with much lower hornblende, augite, hypersthene, and few volcanic glass (Table 5).

Table 4. Chemical, physical, and mineralogical properties of the profile KM1 at Ngadirejo Kidul, Wonogiri, Central Java.

Property and unit	Soil horizon			
	Ap	Bt1	Bt2	Bt3
Depth (cm)	0-15	15-31	31-62	62-89
Clay (%)	47	88	88	86
pH (H_2O)	4.90	5.80	5.90	5.80
Organic-C (%)	1.00	0.39	0.71	0.23
Organic-N (%)	0.08	0.05	0.05	0.03
HCl 25% extractable				
P_2O_5 (mg kg^{-1})	620	190	230	390
K_2O (mg kg^{-1})	100	80	90	130
Olsen P_2O_5 (mg kg^{-1})	43	8	12	18
Exchangeable cation (cmol(+) kg^{-1})				
Ca	6.20	8.70	8.00	7.40
Mg	1.30	2.20	2.60	2.60
K	0.10	0.10	0.10	0.20
Na	0.10	0.30	0.40	0.30
Sum	7.70	11.30	11.10	10.50
CEC pH 7	15.10	12.50	12.60	11.40
Effective CEC (cmol(+) kg^{-1})	13.50	12.80	12.60	12.20
Base saturation (%)	90.00	100.00	100.00	100.00
P retention (%)	9.80	10.00	15.80	14.10
Bulk density (g cm^{-3})	0.90	1.16	Nd	Nd
Total pores (% vol.)	66.00	56.30	Nd	Nd
Available water capacity (% vol.)	8.50	13.10	Nd	Nd
Permeability (cm/hr^{-1})	9.14	2.97	Nd	Nd
Sand fraction mineral (%)				
Opaque	65	79	57	65
Zircone	Sp	Sp	Sp	Sp
Quartz	10	13	22	17
Limonate	Sp	-	-	Sp
Opaline	Sp	Sp	1	Sp
Mineral fraction	2	1	4	1
Rock fragments	4	3	14	17
Volcanic glass	Sp	Sp	Sp	Sp
Plagioclase	6	1	Sp	Sp
Feldspar	Sp	Sp	Sp	Sp
Mica	-	Sp	Sp	Sp
Hornblende	2	1	1	Sp
Augite	4	Sp	Sp	-
Hypersthene	7	2	Sp	Sp
Total	100	100	100	100
Crystalline clay minerals (<2 mm)	Pl > Cr > Rf = Qz		Pl > Cr > Rf = Qz	

Minerals: Qz = quartz; Pl = plagioclase; Rf = rock fragment; Cr = crystolite.
Sp = <1%; Nd = not determined.

Morphological properties of the soil profile KM2 showed a horizon sequence of Ap - Bg - Bssg1 - Bssg2 - Bssg3 - BCssg. The surface horizon (Ap) was characterized by dark bluish gray (5B 4/1) color, clay texture, firm consistency, and slightly alkaline reaction (pH 8.3). The lower horizons showed dark gray (5Y 4/1) color, clay texture, firm consistency, slickenside features, and slightly alkaline reaction (pH 8.4). The slickensides had vertic properties caused by the shrinking and swelling of clay minerals.

The surface horizon consisted of high clay fraction (79%), low organic C, low total N, high available P_2O_5 (42 mg kg^{-1}), and medium total K_2O (310 mg kg^{-1}). The relatively high CEC (24.1 cmol(+) kg^{-1}) of this horizon was dominated by Ca (59.5 cmol(+) kg^{-1}) and Mg (3.4 cmol(+) kg^{-1}). The sub-surface horizons had irregular high clay content with depth (38-84%), followed by irregular decrease in CEC at pH 7 (20.1-32.4 cmol(+) kg^{-1}), medium to high available P_2O_5 (16-19 mg kg^{-1}), and medium potential K_2O (320-360 mg kg^{-1}). The

Table 5. Chemical, physical, and mineralogical properties of the profile KM2 at Krangganhardjo, Grobogan, Central Java.

Property and units	Soil horizon				
	Ap	Bg	Bssg1	Bssg2	Bssg3
Depth (cm)	0-19	19-34	34-52	52-72	72-79
Clay (%)	79	38	80	75	84
pH (H_2O)	8.30	8.40	8.40	8.40	8.40
Organic-C (%)	1.18	0.53	0.54	0.45	0.38
Organic-N (%)	0.09	0.06	0.05	0.04	0.03
HCl 25% extractable					
P_2O_5 (mg kg^{-1})	1,580	900	800	850	680
K_2O (mg kg^{-1})	310	320	320	320	360
Olsen P_2O_5 (mg kg^{-1})	42	18	16	19	16
Exchangeable cation (cmol(+) kg^{-1})					
Ca	59.50	66.80	60.50	61.50	60.50
Mg	3.40	1.90	1.60	1.60	1.70
K	0.30	0.30	0.30	0.30	0.40
Na	0.20	0.60	0.70	0.70	0.80
Sum	63.40	69.60	63.10	64.10	63.00
CEC pH 7	24.30	32.00	32.40	21.40	20.10
Base saturation (%)	100.00	100.00	100.00	100.00	100.00
Apparent CEC pH 7 (cmol(+) kg^{-1} clay)	30.60	84.20	40.50	28.50	23.90
$CaCO_3$ (%)	17.60	19.40	17.80	19.00	21.40
Bulk density (g cc^{-1})	0.96	1.23	Nd	Nd	Nd
Total pores (% vol.)	63.70	53.50	Nd	Nd	Nd
Drainage pores (% vol.)					
Fast	9.60	6.80	Nd	Nd	Nd
Slow	5.90	4.50	Nd	Nd	Nd
Permeability (cm $hour^{-1}$)	8.69	3.74	Nd	Nd	Nd
Sand fractions (50-200 µm)					
Opaque	4	1	6	4	8
Zircone	6	-	6	6	Sp
Quartz	26	21	22	25	28
Opaline silica	6	1	-	8	8
Zeolite	2	1	2	1	2
Mineral fragments	Sp	1	1	2	2
Rock fragments	2	8	3	4	2
Volcanic glass	1	1	Sp	1	Sp
Plagioclase	48	48	43	41	36
Feldspar	2	3	6	3	3
Hornblende	8	10	9	11	12
Augite	3	3	4	6	3
Hypersthene	4	2	3	2	4
Epidote	Sp	Sp	1	Sp	Sp
Garmet	-	-	Sp	-	Sp
Total	100	100	100	100	100
Clay fractions(<2 µ)	Sa >>> Qz = Ca > Ka		Sa >>> Qz = Ca > Ka		

Minerals: Sa = saponite; Qz = quartz; Ka = kaolinite; Ca = calcite;
Sp = <1%; Nd = not determined.

presence of calcium carbonate causes slightly alkali soil reaction (pH 8.4) followed by high Ca in the exchange cation complex.

Morphological properties and laboratory analysis data of soil in Grobogan show that it belongs to the *Typic Haplustert* subgroup (Soil Survey Staff 2003), while at the family level the soil could be classified as *very-fine, mixed, isohyperthermic Typic Haplustert.* This soil had a relatively high nutrient contents, except for organic-C and N. The high soil pH and high Ca in the exchange complex may influence the available P_2O_5. Clay content with shrinking and swelling characteristics (smectite) may also pose some difficulties in soil preparation. Applying organic matter, mulching, and N fertilizers with acid reactions such as ammonium sulfate, and irrigation will be important for maize planting.

Soil Characteristics on SSNM Experimental Sites in East Java

The study areas were located in rice field of Wonokerto and Mojoayu (Kediri District), and in dry farming area of Prunggahan (Tuban District). Geographic position of the first location, profile KM3 in Wonokerto, is at 112°12'30" East and 7°35'25" South. The second location, profile KM4 in Mojoayu, was at 112°12'35" East and 7°35'27" South and the third location, profile KN2 Tuban was at 112°04' 50" East and 6°57'08" South.

Wonokerto, Kediri (KM3)

Studied soil in Wonokerto was situated on alluvial plain containing recent sandy volcaniclastic materials. Sand fractions of the soil consisted of many rock fragment, labradorite, augite, and hypersthene, while volcanic glass, biotite, hornblende were few (Table 6). The soil profile developed on flat topography (<3% slope) with slightly poor drained and at 158 m asl.

Climate in Wonokerto was characterized by the mean annual rainfall of 1,545 mm with 3 wet months (>200 mm month^{-1}) and 5 dry months (<100 mm month^{-1}). Air temperature ranged between 25.6°C and 27.5°C with an average of 26.5°C. Based on the rainfall data, the climate could be classified as D3 agro-climatic zone and soil moisture regime of the site in Soil Taxonomy (Soil Survey Staff 1998) is *Ustic.* Soil temperature regime could be classified as *Isohyperthermic.*

Morphological properties of the studied soil had a horizon sequence of Ap - Bw - Bwg - BCg - Cg. The surface horizon was characterized by very dark gray (10YR 3/1) color, loamy sand texture, sub-angular blocky structure, and neutral reaction (pH 7.5). It had very low organic-C (0.44%) and total N contents (0.04%), very high potential P_2O_5 (620 mg kg^{-1}) and available P_2O_5 (40 mg kg^{-1}), but very low total K_2O content (80 mg kg^{-1}). The CEC of this soil was very low (2.5 cmol kg^{-1}) because of the coarse texture, and the base saturation was very high (100%). The cation exchange complex was dominated by Ca and Mg.

The sub-surface horizons had dark brown (10YR 4/3) to gray (10YR 5/1) color, loamy sand texture mixed with many gravels at the lower horizons, massive and granular structure, and neutral to slightly alkali reaction. It had lower organic-C and total N contents and lower potential and available P_2O_5 and lower base saturation than the surface horizon. The exchange site was saturated by bases leading to 100% base saturation.

Under the *ustic* soil moisture regime, morphological, mineralogical, physical, and chemical properties of the soil in Wonokerto fulfills the requirement for *Aquic Haplustept* subgroup of Soil Taxonomy Classification (Soil Survey Staff 2003). At the family level, the soil can be classified as *sandy, mixed, isohyperthermic Aquic Haplustept.*

In general, the soil in Wonokerto has some constraints for plant growth, including coarse texture, very low organic-C, low total N, K, and CEC. Water stress may occur as a result of low water holding capacity due to the soil’s coarse texture and low organic matter content. The very low CEC indicates that the nutrient retention of the soil is also low, such that nutrients easily leach from surface layer. The high base saturation indicates the potential amount of bases that could be released from the weathering of reserved minerals, such as volcanic glass, hornblende, augite, and hypersthene. Therefore, addition of organic matter and fertilizers, as well as good water supply is very important for agriculture activities.

Mojoayu, Kediri (KM4)

The research site in Mojoayu was located at about 25 km east of Kediri with an elevation of 160 m asl. Physical environments of this site, such as climate, landform, parent material, and land use were almost the same as the site in Wonokerto. However, soil at this site developed from finer (clayey) alluvial.

Morphological properties of soil in Mojoayu (KM4) had a horizon sequence of Ap - Bwg1 - Bwg2 - BCg. The surface horizon (Ap) was characterized by olive brown (2.5Y 4/3) color, clay texture, massive structure, firm consistency, and slightly alkaline reaction (pH 7.7). The sub-surface horizons were characterized by light grayish-brown (10YR 4/2) to dark brown (10YR 4/3) colors with many black (10YR 3/1) and dark gray (10YR 4/1) mottles, clay texture, angular blocky structure with clear slickensides, firm consistency, and slightly alkaline reaction (pH 8.0-8.3).

The chemical data show that the surface horizon consisted of high clay fraction (61%), very low organic-C (0.78%) and total N (0.08%), low available P_2O_5 (21 mg kg^{-1}), and low total K_2O (120 mg kg^{-1}). The exchange sites (with CEC of 22.1 cmol(+) kg^{-1}) were dominated by Ca and Mg (22.1 and 8.0 cmol kg^{-1}),

Table 6. Chemical, physical, and mineralogical properties of the profile KM3 at Wonokerto, Kediri, East Java.

Property and unit	Soil horizon			
	Ap	Bw	Bwg	BCg
Depth (cm)	0-23	23-40	40-65	65-87
Texture classes	LS	LS	LS	LS
pH (H_2O)	7.50	7.80	7.70	7.30
Organic-C (%)	0.44	0.08	0.04	0.08
Organic-N (%)	0.04	0.01	0.01	0.01
HCl 25% extractable				
P_2O_5 (mg kg^{-1})	620	550	540	600
K_2O (mg kg^{-1})	80	80	80	130
Olsen P_2O_5 (mg kg^{-1})	40	9	0	11
Exchangeable cation (cmol(+) kg^{-1})				
Ca	8.10	5.70	5.00	6.80
Mg	1.60	0.80	0.80	1.20
K	0.10	0.10	0.10	0.10
Na	0.30	0.50	0.40	0.70
Sum	10.10	7.10	6.30	8.80
CEC pH 7	2.50	1.80	1.90	2.90
Base saturation (%)	100.00	100.00	100.00	100.00
Bulk density (g cc^{-1})	1.27	1.44	Nd	Nd
Total pores (% vol.)	52.00	45.50	Nd	Nd
Drainage pores (% vol.)				
Fast	25.20	20.00	Nd	Nd
Slow	4.50	4.30	Nd	Nd
Available water	10.30	11.30	Nd	Nd
Permeability (cm $hour^{-1}$)	8.66	5.45	Nd	Nd
Sand fractions (50-200 µm)				
Opaque	12	20	14	6
Quartz	Sp	-	-	-
Opaline silica	Sp	Sp	-	-
Zeolite	Sp	Sp	-	-
Mineral fragments	Sp	Sp	-	-
Rock fragments	23	24	26	45
Volcanic glass	1	1	1	2
Plagioclase	32	23	25	24
Sanidine	Sp	-	-	-
Hornblende	1	1	1	2
Augite	15	12	19	8
Hypersthene	16	19	14	13
Total	100	100	100	100
Clay fractions(<2µ)	Pl > Il = Cr = Qz		Pl > Il = Cr = Qz	

Mineral: Pl = plagioclase; Qz = quartz; Cr = crystobalite; Il =illite.
Sp = <1%; Nd = not determined.

respectively causing very high (100%) base saturation. The sub-surface horizons were characterized by considerably lower organic-C, total N, potential P_2O_5 and available P_2O_5 than the surface horizon. Sub-surface horizons also had slightly higher contents of clay fractions (69-77%) and slightly higher CEC (22.7-28.2 cmol(+) kg^{-1}). The high exchangeable cations and low CEC at pH 7 resulted in a base saturation of 100% (Table 7).

The mineralogical composition of the sand fractions shows many rock fragments and volcanic minerals, such as volcanic glass, hornblende, augite, and hypersthene. Although the sand fractions are low in this soil, the volcanic minerals in those sand fractions are important as reserved minerals for some nutrients (Table 7).

In Soil Taxonomy classification (Soil Survey Staff 2003), morphological properties and laboratory data of the soil in Mojoayu meet the requirement for *Chromic Haplustert* subgroup and in the family level can be classified as *very-fine, mixed, isohyperthermic Chromic Haplustert.*

In general, chemical and mineralogical characteristics of this soil are suitable for growing agricultural

Table 7. Chemical, physical and mineralogical properties of the profile KM4 at Mojoayu, Kediri, East Java.

Property and unit	Soil horizon			
	Ap	Bssg1	Bssg2	BCssg
Depth (cm)	0-23	23-44	44-96	96-120
Clay (%)	61	69	75	77
pH H_2O	7.70	8.00	8.20	8.30
Organic-C (%)	0.78	0.30	0.20	0.15
Organic-N (%)	0.08	0.03	0.02	0.02
HCL 25% extractable				
P_2O_5 (mg kg^{-1})	220	110	90	100
K_2O (mg kg^{-1})	120	100	100	100
Olsen P_2O_5 (mg kg^{-1})	21	12	8	37
Exchangeable cation (cmol(+) kg^{-1})				
Ca	22.10	24.50	21.20	20.00
Mg	8.00	12.60	19.70	22.80
K	0.20	0.10	0.10	0.20
Na	0.70	1.60	2.80	3.20
Sum	31.00	38.80	43.80	46.20
CEC pH 7	13.30	22.70	22.80	28.20
Base saturation (%)	100.00	100.00	100.00	100.00
Apparent CEC pH 7 (cmol kg^{-1})	21.80	32.90	30.40	60.00
$CaCO_3$ (%)	2.40	2.10	2.40	2.60
Bulk density (g cc^{-1})	1.19	1.24	Nd	Nd
Total pores (% vol.)	55.10	53.20	Nd	Nd
Fast	13.30	8.70	Nd	Nd
Slow	5.30	4.60	Nd	Nd
Available water capacity (% vol.)	5.30	4.60	Nd	Nd
Permeability (cm hr^{-1})	12.14	8.87	Nd	Nd
Sand fractions (50-200 µm)				
Opaque	7	5	9	7
Zircone	Sp	-	-	-
Quartz	Sp	1	2	1
Opaline silica	Sp	-	-	
Zeolite	Sp	Sp	Sp	
Mineral fragments	Sp	-	-	
Rock fragments	22	31	25	
Volcanic glass	2	1	1	
Plagioclase	24	25	28	
Feldspar	Sp	Sp	Sp	
Hornblende	22	15	14	
Augite	8	10	9	
Hypersthene	15	12	12	
Total	100	100	100	100
Clay fractions(<2µ)	Pl > Il = Cr = Qz		Pl > Il = Cr = Qz	

Mineral: Qz = quartz; Pl = plagioclase; Il = Illite; Cr = crystobalite.
Sp = <1%; Nd = not determined.

crops. The high clay content and very sticky consistency in wet condition may cause some difficulties for soil preparation. Furthermore, the soil can become very hard and cracked in dry season. This condition needs a special technique in soil preparation. The relatively low contents of organic-C, N, available P_2O_5, and K in the surface horizon imply that to get satisfactory maize yield, this soil will need high inputs of organic matter, N, P and K fertilizers.

Prunggahan, Tuban (KN2)

The studied area is located in Prunggahan Village about 100 km from Tuban. According to Oldeman (1975), climate in this area had an annual rainfall of 1,600 mm and in the agro-climatic map of Java, the area (Tuban) is situated in the E3 zone, characterized by less than three consecutive wet months (>200 mm month^{-1}) and at least five dry months (<100 mm month^{-1}) in a year. Air temperature in Tuban ranged from 24.6°C to 26.7°C and the mean annual air temperature was 25.7°C. Soil temperature regime according to Soil Taxonomy is *Isohyperthermic* and the soil moisture regime is *Ustic*.

The studied area is located on alluvial and collovial plain forming flat to undulating land. Soils in this area developed from volcaniclastic sediments and sand fractions of this soil were dominated by quartz, but few weatherable minerals indicating that the soil may formed from pre-weathered sediment material, mixed by volcanic material.

Morphological properties of soil profile (KN2) in Prunggahan (Tabel 8) show a very deep solum (180 cm depth) with a horizon sequence of Ap - Bt1 - Bt2 - Bt3 - Bt4 - Bt5. The Ap horizon was relatively thin (0-12 cm), characterized by reddish-brown (5YR 4/4) color, clay texture, sub-angular blocky structure, and many coarse materials (cobbles). The Bt horizon was reddish-brown in color, clay texture, and sub-angular

Table 8. Chemical, physical, and mineralogical properties of the profile KN2 at Prunggahan, Tuban, East Java.

Property and unit	Soil horizon				
	Ap	Bt1	Bt2	Bt3	Bt4
Depth (cm)	0-12	12-29	29-66	66-80	80-120
Clay (%)	75	55	92	93	92
pH (H_2O)	6.40	5.30	5.40	5.40	5.40
Organic-C (%)	1.61	0.53	0.47	0.28	0.24
Organic-N (%)	0.18	0.07	0.06	0.04	0.03
HCl 25% extractable					
P_2O_5 (mg kg^{-1})	4,930	4,130	4,460	3,950	4,470
K_2O (mg kg^{-1})	540	110	110	90	110
Olsen P_2O_5 (mg kg^{-1})	370	173	242	275	296
Exchangeable cation (cmol(+) kg^{-1})					
Ca	18.10	9.70	10.10	9.50	10.20
Mg	3.40	2.20	1.80	2.60	2.60
K	0.70	0.10	0.10	0.10	0.20
Na	0.10	0.20	0.00	0.20	0.10
Sum	22.30	12.20	12.00	12.40	13.00
CEC pH 7	13.50	9.80	10.80	8.60	10.80
Base saturation (%)	100.00	100.00	100.00	100.00	100.00
$CaCO_3$ (%)	1.22	0.43	0.71	0.39	0.15
$Al^{3}+$ (cmol kg^{-1})	0.00	0.20	0.10	0.00	0.00
Apparent CEC pH7 (cmol kg^{-1})	18.00	17.80	11.20	9.20	11.70
Effective CEC	29.70	22.50	13.20	13.30	14.10
Bulk density (g cc^{-1})	1.18	Nd	1.36	Nd	Nd
Total pores (% vol.)	55.40	Nd	48.60	Nd	Nd
Available water (% vol.)	8.00	Nd	9.80	Nd	Nd
Permeability (cm hour^{-1})	18.80	Nd	5.62	Nd	Nd
Sand fractions (50-200 µm)					
Opaque	6	8	6	4	5
Zircone	Sp	Sp	2	Sp	Sp
Quartz	87	85	88	92	90
Limonite	Sp	Sp	Sp	Sp	Sp
Iron concretion	-	Sp	-	-	-
Zeolite	-	Sp	-	Sp	-
Mineral fragments	2	Sp	Sp	1	1
Rock fragments	4	6	3	3	4
Plagioclase	Sp	Sp	Sp	Sp	Sp
Feldspar	Sp	Sp	1	Sp	Sp
Hornblende	1	Sp	Sp	Sp	Sp
Augite	Sp	Sp	Sp	Sp	Sp
Hypersthene	Sp	Sp	Sp	Sp	Sp
Total	100	100	100	100	100
Clay fractions(<2µ)	Pl > Il = Cr = Qz		Pl > Il = Cr = Qz		

Mineral: Qz = quartz; Pl = plagioclase; Il = illite; Cr = crystobalite.
Sp< = 1%; Nd = not determined.

blocky structure. The coarse materials decreased and disappeared in the lower horizons.

The surface horizon was characterized by high clay fraction (75%), slightly acid reaction (pH 6.4), low organic-C (1.61%), low total N (0.18%), very high potential P_2O_5 (4,930 mg kg^{-1}) and high potential K_2O (540 mg kg^{-1}). CEC at pH 7 of the surface horizon was low (13.5 cmol(+) kg^{-1}), but the sum of basic cation was high (22.3 cmol(+) kg^{-1}) and dominated by Ca and Mg. The sub-soil horizons had higher clay contents (92-93%) and lower contents of organic-C (0.24-0.53%), total N (0.03-0.07%) and CEC pH 7 than the surface horizon. The increasing high clay contents with depth, followed by relatively low apparent CEC at pH 7 (9.2-17.8 cmol(+) kg^{-1} clay) and rather low effective CEC (13.2-22.5 cmol(+) kg^{-1} clay) may indicate the presence of kaolinitic clay, thus fulfilling the requirement for an argillic horizon.

Prunggahan soil had an *ustic* soil moisture regime, an argillic horizon, and high base saturation meeting the requirement for the order *Alfisol* in Soil Taxonomy (Soil Survey Staff 2003). Since the apparent effective CEC of clay is less than 24 cmol(+) kg^{-1}, the soil is classified as a *Kanhaplic Haplustalf* (subgroup). At the family level, the soil can be classified as *very fine, kaolinitic, isohyperthermic Kanhaplic Haplustalf.*

The relatively dry climate of the study area may cause moisture stress to the maize plants. This problem can be solved by manipulating the soil moisture, such as by using supplementary irrigation or mulchin g of plant residues in the soil surface. Soil surface properties also imply that maize plants in this soil would need a relatively high N fertilizer. The high Ca content of this soil may also affect available P_2O_5, therefore using organic matter and acid fertilizer is recommended.

Soil Characteristics on SSNM Experimental Site in South Sulawesi (KN1)

The observed soil was located in Tolo Village, Jeneponto Regency which has a geographical position at 119°48'10" East 5°41'12" South. Climate in the studied area, based on Jeneponto Station, had an annual rainfall of 1,050 mm and in the agro-climatic map of Sulawesi (Oldeman and Sjarifuddin 1977) the area is in zone E3 where there are less than 3 wet months (> 200 mm $month^{-1}$) and 3-5 dry months (<100 mm $month^{-1}$) in a year. Air temperature ranged from 24.6°C to 26.7°C. According to Soil Taxonomy, the soil temperature and soil moisture regime of this area can be classified as *isohyperthermic* and *ustic,* respectively (Soil Survey Staff 2003).

Tolo area is a lower part of the colluvial piedmont of Lompobatang volcano, forming undulating to flat terrain. Soil in this area developed from skeletal tuff materials. Sand fractions of this soil were characterized by many opaque minerals, rock and mineral fragments, followed by a few volcanic minerals like glass, sanidine, hornblende, augite, hypersthene, and glass (Table 9), relating to the tuff as parent material.

Soil profile had a horizon sequence of Ap - C1 - C2 - 2AC1 -2C2 - 3C. The horizon sequence indicates an undeveloped soil which is characterized by very thin surface horizon (Ap), brownish grey (10 YR 4/2) color, loam to clay loam texture with coarser materials (cobbles or stones), and loose to massive structure. Chemical analysis of this soil (Table 9) show that the surface horizon had low clay fractions (17%), acid reactions (pH 4.2), very low organic-C (0.99%), total N (0.10%), and CEC (6.8 cmol(+) kg^{-1}). The properties of lower horizons were almost the same as the surface horizon, but had a higher clay content (21-36%) with coarser materials. In Soil Taxonomy, this soil with *ustic* soil moisture regime meets the requirements for *Typic Usthorthent* subgroup (Soil Survey Staff 2003) and could be classified as *fine silty, mixed, acid, isohyperthermic Typic Ustorthents* at the family level.

Management Implications

Soil profile data demonstrated that the soils at the sites of SSNM for maize represent a wide range of soils and climate - from the young Entisols in the semi-arid area (with 1,050 mm annual rainfall) in Jeneponto to old Oxisols in the humid area with annual rainfall of 2,200 mm in Lampung. This range of representation is important in future research on maize fertilization.

Soil limiting factors and management implications of the study were summarized in Table 10. Organic matter and, in consequence, total N were relatively low for all SSNM sites. Nitrogen should be added based on indigenous N content, estimated N removal with harvest (about 16 kg N t^{-1} of maize grain yield) (Dierolf *et al*. 2001), potential losses through leaching (which is higher in coarse than in fine-textured soils), as well as gaseous losses (about 30-50%).

Most of the soil surfaces in SSNM sites showed fine texture (clay and clay loam), except for the soils in Wonokerto (loamy sand, loam). The quantity and kinds of clay fractions influence the CEC of the studied soils. The high clay content and low-activity clay properties cause very low or low CEC as observed in Lampung and Wonogiri soils. As such, exchangeable cations, especially K, were also low.

Table 9. Chemical, physical, and mineralogical properties of the profile KN1 at Tolo, Jeneponto, South Sulawesi.

Property and unit	Soil horizon		
	Ap	C1	C2
Depth (cm)	0-10	10-30	30-60
Clay (%)	17	21	36
pH (H_2O)	4.20	4.90	5.30
Organic-C (%)	0.99	0.86	0.60
Organic-N (%)	0.10	0.09	0.08
HCL 25% extractable			
P_2O_5 (mg kg^{-1})	3,050	2,280	1,820
K_2O (mg kg^{-1})	290	280	240
Olsen P_2O_5 (mg kg^{-1})	67	43	43
Exchangeable cation (cmol(+) kg^{-1})			
Ca	4.10	8.70	8.80
Mg	0.90	1.30	1.70
K	0.30	0.20	0.20
Na	0.10	0.00	0.00
Sum	5.40	10.20	10.70
CEC pH 7	6.80	7.30	7.40
Base saturation (%)	79.00	100.00	100.00
$CaCO_3$ (%)	0.36	1.14	0.52
$Al^{3}+$ (cmol kg^{-1})	0.80	0.00	0.00
Bulk density (g cc^{-1})	1.48	Nd	1.50
Total pores (% vol.)	44.10	Nd	43.40
Fast	9.10	Nd	8.90
Slow	5.90	Nd	5.30
Available water (% vol.)	8.90	Nd	9.50
Permeability (cm $hour^{-1}$)	9.77	Nd	8.87
Sand fractions (50-200 µm)			
Opaque	44	42	44
Zircone	1	Sp	3
Quartz	7	6	5
Limonite	1	Sp	1
Iron concretion	1	1	Sp
Zeolite	-	Sp	-
Mineral fragments	21	19	15
Rock fragments	16	24	23
Volcanic glass	1	Sp	1
Plagioclase	-	Sp	-
Feldspar	4	7	6
Hornblende	Sp	Sp	1
Augite	3	1	1
Hypersthene	1	Sp	Sp
Total	100	100	100
Clay fractions(<2µ)	Pl > Ka > Cr = Qz		Pl > Ka > Cr = Qz

Mineral: Pl = plagioclase; Ka = kaolinite; Cr = crystobalite; Qz = quartz.
Sp = <1%; Nd = not determined.

Thus, these soils require not only relatively high amount of K, but also organic matter inputs. K fertilization is also needed for maintaining K levels at relatively high-K status soils like the Karo, Grobogan, and Tuban sites unless plant residues are recycled (Aggarwal *et al*. 1997; Andrist-Rangel *et al*. 2007).

Most of the studied soils had medium or high to very high potential (25% HCI extractable) P_2O_5, but the available P_2O_5 (Olsen P_2O_5) varied from low to high. The available P_2O_5 in the studied soils seems to be influenced by the high concentration of Ca or the presence of carbonate (high soil pH), such as in Grobogan, Wonokerto, and Mojoayu soils. Using an acidifying fertilizer, such as ammonium phosphate, may solve this problem. Fertilization should also take into account indigenous supply of P, removal through harvest (about 3 kg P t^{-1} of grain yield), and possible fixation by Ca in high pH soils.

Table 10. Soil classification, limiting factors, and generalized management recommendation for each site of the SSNM.

Profile code and site name	Soil classification and limiting factors	Recommended intervention
AF1, Karo	*Andic Eutrudept* Low CEC and low total N	Addition of organic matter and N, and maintenance fertilizers for P and K
AF2, Lampung	*Typic Hapludox* Low CEC, low pH, very low total N	Addition of organic matter, N, P, K fertilizers
KM1, Wonogiri	*Rhodic Kanhaplustalf* Low pH and very low total N	Addition of organic matter, N, P, K fertilizers
KM2, Grobogan	*Typic Haplustert* Shrinking and swelling	Addition of organic matter and soil drainage management, N and P fertilizers and K maintenance
KM3, Wonokerto, Kediri	*Aquic Haplustept* Coarse texture, very low CEC and very low total N	Addition of organic matter, N, P, K fertilizers, split application of K to reduce leaching loss
KM4, Mojoayu, Kediri	*Chromic Haplustert* Poor drainage, shrinking swelling, and very low total N	Addition of organic matter, N and P fertilizers, drainage treatment, and K maintenance
KN2, Tuban	*Kanhaplic Haplustalf* Clay texture, low CEC, low total N	Addition of organic matter and N fertilizer, P and K maintenance fertilization
KN1, Jeneponto	*Typic Ustorthent* Very low pH	Addition of organic matter, N and K fertilizers, and P maintenance fertilization

The high exchangeable Ca and Mg may have been influenced by the presence of carbonate materials and weatherable minerals (hypersthene, augite, and hornblende), such as in Grobogan, Mojoayu, Karo, and Tuban soils. The neutral to basic soil pH and the medium to high available Ca and Mg in most of the soils indicate that these soils do not need liming.

Organic matter inputs may increase the soil CEC, water-holding capacity for sandy soils, and porosity for high clay soils. In addition, organic matter can supply various kinds of macro- and micro-nutrients (Watson *et al*. 2002). In general, organic matter input is needed in all SSNM experimental sites because all the soils have low or very low organic carbon and total N contents. The easiest source of organic matter is plant residues, which are high in K and could be used as mulch, especially in the low rainfall areas, or be processed into compost before application. Barnyard manure is also an important organic matter source which contains appreciable amounts of N, P, and K as well as micro-nutrients (Agus *et al*. 2009). Other organic matter sources, such as industrial wastes and green leaf manure could also be explored.

CONCLUSION

This research has provided a comprehensive soil database not only for maize production but also for other crops in the research areas. For all areas studied, organic matter management including recycling of at least crop residues is strongly recommended due to low organic matter content and low organic nitrogen. N, P, and K fertilizers are needed to support intensive maize production system. For high K status soils in Karo, Grobogan, Mojoayu, and Tuban, relatively low K fertilizer application or otherwise plant residue recycling would suffice plant K need. Exact fertilization rates would have to be adjusted based on the calculation of expected yield, field nutrient status, and estimates of nutrient losses.

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