BIOPHYSICAL CHARACTERISTICS OF DRY-CLIMATE UPLAND AND AGRICULTURE DEVELOPMENT CHALLENGES IN WEST NUSA TENGGARA AND EAST NUSA TENGGARA PROVINCES

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Keywords

Chemical and physical properties, upland, land management, water availability, conservation agriculture, West and East Nusa Tenggara

Abstract

West Nusa Tenggara Province (NTB) and East Nusa Tenggara (NTT) has an area of about 6.6 million ha, of which largest part (95%) categorized has dry-climate with annual rainfall <2,000 mm and has 5-8 dry months. In fact, about 1.56 million ha or 25% of the area has 8-10 dry months with annual rainfall <1,000 mm. To identify the soil characteristic, the soil analyses have been conducted in 12 soil profile, 57 composite soil sample, and undisturbed soil ring. Soil samples were analyzed for chemical properties such as texture, pH, nutrient content, C, N, P, K, cations exchangeable, cationa exchange capacity (CEC), basa saturated (BS), and for physical properties such as water content, bulk density, total pore space, water holding capacity and permeability. The results showed good fertility status at three islands which is characterized by neutral to basic soil acidity, medium to high P and K total content, high sum of cations, high CEC and high to very high BS. Except for several observation at South West Sumba and West Sumba, which have acidic pH caused by andesitic lava parent material and >2000 mm rainfall lead to high leaching. From 57 composite soil sample showed correlation among chemical and physical properties, such as texture, organic-C, CEC, bulk density (BD), total pore space and water content. The higher sand content lead to smaller CEC. The higher organic-C content, the smaller BD and the higher total pore space. Soil texture may influence water content where the higher sand content, the lesser capacity to hold water and nutrient. The fertility status of the three islands is quite good but low organic carbon (OC) content indicated special attention to improve soil quality in all islands. Thus the land management of upland dry-climate area should be focused on surface water availability (pond, borehole, river) and conservation agriculture. Water supply availability during the dry season will be important for upland dry-climate agriculture development especially for short-lived vegetable crops to increase farmers daily incomes.

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INTRODUCTION

Western part of Indonesia mostly dominated by wet-climate with annual rainfall> 2000 mm per year. From the total about 188.2 million ha, approximately 142.9 million ha (76%) were in wet-climate regions, and widely spread in Sumatra and Kalimantan. In contrast, the Eastern part of Indonesia mostly dominated by dry-climate with annual rainfall <2,000 mm per year. those areas were found around 45.3 million ha (24%) located in East Kalimantan, East Java, part of Sulawesi, North Maluku, Maluku, Bali, West Nusa Tenggara and East Nusa Tenggara (Balitklimat, 2003; Mulyani *et al*., 2010).

Land characteristics of wet-climate regions generally experience intensive nutrient (base cations) leaching and left behind the aluminum silica, which is acid with pH <5. Soil types of the region were dominated by Ultisols, Inceptisols and Oxisols. (Subagyo *et al*, 2000 and Mulyani *et al*., 2003). Oppositely, soil properties in the Eastern part Indonesia with low rainfall mostly contain alkali cations resulting to the level of pH ranging from neutral to slightly alkali (pH 6.0-7.5). Soil types of the Eastern part of Indonesia usually dominated by Alfisols, Mollisols and Entisols. In dry-climates zone, the soil formation and weathering may not as intensive as wet-climate regions resulting to shallow and rocky soil solum (Lithic properties).

In East Nusa Tenggara (NTT) Province with 4.6 million ha of total land, about 3.3 million ha categorized as dry-climate regions, and even around 1 million ha, categorized as very dry regions or semi-arid with annual rainfall <1,000 mm, and the rest of 0.3 million ha have annual rainfall >2.000 mm. Similarly in West Nusa Tenggara (NTB) Province with about 2 million ha of total land, around 69% have annual rainfall 1000-2000 mm and 25% have annual rainfall <1,000 mm (Balitklimat, 2003; Mulyani *et al*., 2010).

Besides having dry climates, shallow solum and rocky soil, NTT and NTB provinces also covered by around 71-75% of hilly topography (Puslitbangnak, 2001). Therefore, not many crops suitable to be cultivated in this area compared to western part of Indonesia, probably due to the biophysical properties and inadequate water availability. As a result, optimization of land use and land management system that combines integrated crop-livestock-water will be an important key to improve the productivity of land. This paper will review the characteristics of soil and climate, the potential and challenges of agricultural development in dry climates upland in the NTB and NTT provinces.

MATERIALS AND METHODS

To recognize the general overview of the land resources and climate in dry- climate region at NTB and NTT provinces, an exploration scale data analysis have been prepared from Indonesia land resources databases (Puslitbangtanak, 2000) and from climate type and rainfall patterns databases (Balitklimat, 2003). To verify their land use, data from Beaureu of Statistic (BPS,2012) was used, and the directives national agriculture layout data was used for potential agriculture expansion (Puslitbangtanak, 2002).

To discover detailed biophysical characteristics, soil survey and soil profiles samples has been collected to represent each province, such as 4 soil profiles from Lombok Island (NTB), 4 soil profiles from Sumba Island (NTT), and 4 soil profiles from Timor Island (NTT). Composite data collected from topsoil (0-20 cm) were utilized to correlate the soil chemical and physical properties. Sampling sites were selected based on the location of the FAO project in conducting the conservation agriculture. The result of this survey was used as baseline condition of biophysical properties of the sites.

The soil observation parameters cover morphological characteristics (soil depth, color, texture, field-pH, structure, consistency, coarse material, cementation, etc.) and environmental conditions (soil drainage, depth, slope, and soil classification) using FAO Method (FAO, 1990), Soil Survey Manual (Soil Survey Division Staff, 1993) and Soil Observation Manual (Balittanah, 2004). Soil was classified using Keys to Soil Taxonomy method (Soil Survey Staff, 2010). Soil samples were undertaken from each layer of the soil profile and undisturbed soil samples was taken using a ring sample.

Soil samples were analyzed to characterize soil physical, chemical, and biological properties including soil texture at three fractions (sand, silt, and clay), organic matter content (C, N, and C/N), soil reaction (pH), potential P_2O_5 and K_2O content (25% HCl extraction), available P_2O_5 (Bray 1 or Olsen methods), P retention, exchangeable cations (Ca, Mg, K, and Na), cation exchange capacity (NH_4OAc pH-7 methods), base saturation, 1 N KCl Al-extraction, Al saturation. Soil physics analysis consists of bulk density, soil permeability and total pore space (pF).

RESULTS AND DISCUSSION

Biophysical Characteristic of Land Resources in NTB and NTT Provinces

Soil General Characteristics

The study results indicate that the soil type found in NTT and NTB provinces derived from different parent materials such as alluvium, limestone, coral reef, sediment, sedimentary limestone, and volcanic; and classified into 5 different soil orders, i.e. Inceptisols, Alfisols, Vertisols, Mollisols, and Entisols (Table 1). In the NTT Province, the widest distribution of soil parent material is sediment, followed by volcanic and limestone, resulting in Inceptisols soil type (Haplustepts) around 2.4 million ha. In NTB Province, parent material was dominated by volcanic for around 1.6 million ha or 80% of the total land, resulting in widest spread of Inceptisols (Haplustepts).

In NTT Province, Haplustepts usually associated with Ustorthents, in which Haplustepts located in the bottom of valley with deep solum. In contrary, Ustorthents usually located at steep slope of valley with shallow solum. Soil formation in dry-climate area may lower than in wet-climate area such as in Sumatra and Kalimantan resulting to NTT Province is dominated by shallow solum.

Table 1. The distribution of soil type based on the parent material at NTB & NTT provinces

Parent material	Soil association		NTB	NTT	Total (ha)
	Soil 1	Soil 2			
Aluvium	Endoaquepts	Halaquepts		16.917	16.917
		Udifluvents		39.139	39.139
	Haplusterts	Endoaquepts	93.003	68.568	161.571
		Haplustepts	9.374	149.146	158.520
	Udipsamments	Endoaquents	1.897	3.045	4.942
Aluvium Total			*104.274*	*276.815*	*381.089*
Limestone	Haplustepts	Haplustalfs	7.830	32.728	40.558
		Ustorthents	48.416	287.580	335.996
	Haplustolls	Haplustepts		113.708	113.708
		Ustorthents	62.934	106.294	169.228

Limestone Total			*119.180*	*540.310*	*659.490*
Reef	Haplustolls	Ustorthents		268.836	268.836
Total Reef				268.836	268.836
Plutonic	Haplustepts	Ustorthents		13.895	13.895
	Haplustolls	Haplustepts		28.306	28.306
	Plutonic Total			*42.201*	*42.201*
Sediment	Haplustepts	Haplustalfs	102.820	191.041	293.861
		Ustorthents	13.278	1.315.643	1.328.921
	Haplusterts	Haplustepts	69.019		69.019
	Haplustolls	Argiustolls	3.092	195.269	198.361
	Paleustults	Haplustepts		45.936	45.936
Sediment Total			188.209	1.747.889	1.936.098
Calcareous sed-iment	Hapludolls	Eutrudepts		34.447	34.447
	Haplustolls	Haplustepts		64.702	64.702
Calcareous sediment total				99.149	99.149
Volcanic	Eutrudepts	Endoaquepts	2.660	11.411	14.071
		Hapludalfs	42.196		42.196
		Udipsam-ments	25.471	9.833	35.304
	Hapludands	Dystrudepts	9.072	45.627	54.699
		Endoaquepts		30.415	30.415
		Eutrudepts	117.418	110.475	227.893
	Hapludolls	Argiudolls		52.281	52.281
	Hapludults	Dystrudepts		42.530	42.530
	Haplustepts	Haplustalfs	1.091.188	387.461	1.478.649
		Haplustolls		103.555	103.555
		Ustipsam-ments	51.353	827	52.180
		Ustorthents	140.663	81.885	222.548
	Haplusterts	Haplustepts	29.699	111.752	141.451
	Haplustolls	Argiustolls		182.542	182.542
		Haplustalfs		62.634	62.634
		Haplustepts		292.279	292.279
	Ustipsam-ments	Haplustands	79.735	61.502	141.237
Volcanic total			1.589.455	1.587.009	3.176.464
	Total		2.001.118	4.562.209	6.563.327

In Central Sumba, nutrient leaching is higher than other locations due to higher annual rainfall of average >2,000 mm and derived from sedimentary parent materials which lead to low pH for about 4.1-4.3 and low cations exchange capacity (CEC) of soil (Mulyani *et al*., 2007). Similarly stated by Subagyo *et al*. (2000) that the region has >2,000 mm rainfall will be dominated by Inceptisols.

In NTB province, the dominant Haplustepts was associated with Haplustalfs covering 1.2 million ha and was located in hilly and mountainous areas with slopes for >15%, having almost the same pattern as NTT province. The next dominant soil was associated between Haplusteps and Ustorthents, which distributed at the rolling and hilly land. Soil type in flat area was dominated by Haplusterts associated with Endoaquepts and mostly used for paddy fields.

Results of soil observation in Lombok island showed that soil mostly derived from volcanic tuff with sandy texture in the top layer. In Ende, Flores Island, Haplustolls soil derived from volcanic parent material with a high sand content of approximately 50-60% (Chendy *et al*, 2003). In contrast, soils derived from limestone mostly have clayey texture. Soil texture affects the CEC where the coarser texture may lead the lesser CEC, indicating the ability of the soil to hold nutrients and water are smaller.

In Sumba Island, soil mostly have low pH due to andesitic lava parent material (pH ranged from 4.4-5.2). pH level of soil associated with higher rainfall for about >2.000 mm per year in Southwest Sumba. Low soil pH may affect physiological plant growth by accumulation of aluminum, hydrogen, iron, sulfate (Sanchez, 1976). In Timor Island of NTT, the soil pH is neutral to alkaline. Although the soil was derived from alluvium, the surrounding parent material was entirely made of limestone. Soils derived from limestone parent material has shallow solum <50 cm and mostly have lithic properties.

Undisturbed samples collected from NTB and NTT Provinces indicated bulk density (BD) of was >1.0 g/cm^3, except for Sumba Island. Organic matter can improve soil aggregation, increase the nutrients availability and increase the soil water holding capacity. Soil bulk density indicates the ease of cultivation and the ability to support the growth of plant roots and soil aeration aspects of root penetration.

Soil organic carbon content (%) in the most of samples collected and analysed in Lombok and Timor are classified as very low, but in Sumba it indicated relatively higher than other location. The analysis concluded that the Organic C content in the majority of soils (93%) in Timor is very low. In Lombok, all soil samples are categorized in very low to low soil Organic C content while in Sumba 48% are very low to low and 52% with moderate to high. This indicated that all location of selected sites need to be increased the organic C content of soil. Whit this FAO project, by applying conservation agriculture through return trash to land, no or minimum tillage and plant rotation may improve soil quality and improves water holding capacity of soil.

Table 2: Soil C organic content is summarized in the table below.

Level of Organic C content	Timor Number of sample	%	Lombok Number of sample	%	Sumba Number of sample	%
Very low (Below 1 %)	24	35.82	33	76.74	22	32.84
Low (1 – 2 %)	38	56.72	10	23.26	10	14.93
Moderate (2 – 3 %)	5	7.46			17	25.37
High (3 – 5 %)					17	25.37
Very high above 5 %					1	1.49
Total	67	100	43	100	67	100

Relationship amongst soil properties in NTB and NTT Provinces is presented in Figure 1. In general, higher sand content tend to have a lower soil CEC. Organic-C content affects the soil BD, total pore space, water and microorganisms. Stevenson (1982) stated that the addition of organic matter will improve the overall condition of soil physical, biological and chemical properties. According to Rees *et al.* (2000), organic matter is a source of nutrients for plants as well as energy sources for soil organisms. Management of soil organic matter is one of the activities for the soil quality evaluation and plays an important role in supporting soil productivity significantly on sustainable agricultural systems. In Figure 1 appears that the higher organic matter tend to have lower soil bulk density and the higher total pore space.

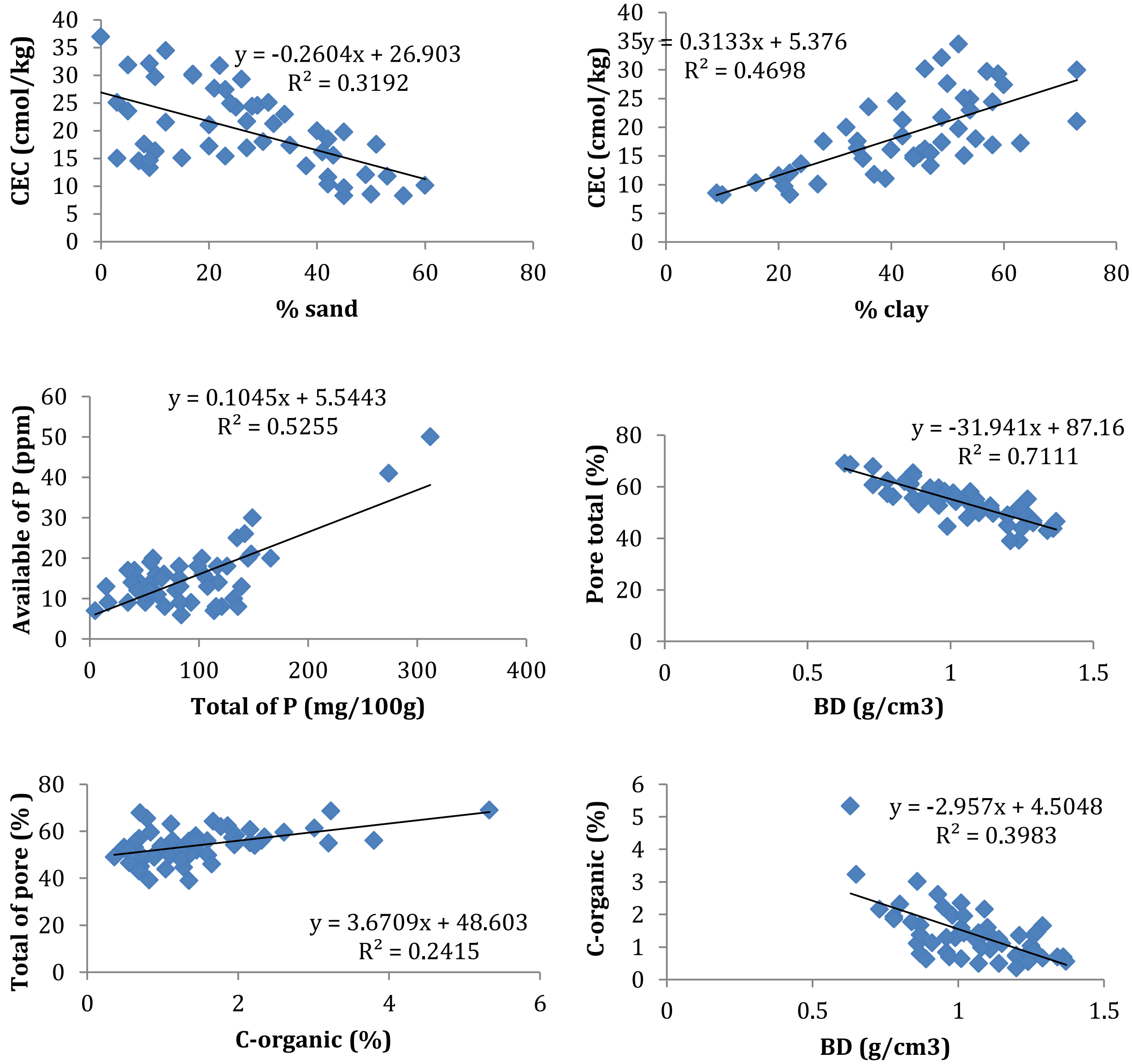

Figure 1: The relationship amongst soil properties

General Climate Characteristics

Rainfall distribution and climate type (Balitklimat, 2003) in NTB and NTT is presented in Table 3. Rainfall of IIA with indicate of 5-8 dry-months and <4 wet-months was cover around 2.3, million ha in NTT and widely distributed around the hills and mountains with slopes> 15%. This indicated that soil may susceptible to erosion. Widiyono *et al*. (2006) stated that the loss of soil through erosion occurred around 11 t/ha/year in Kupang and Timor Island.

Table 3: Rainfall distribution and climate type at NTB and NTT provinces

Rainfall pattern	Climate type	Rainfall (mm)	NTB	NTT	Total
IA	Dry climate	< 1000	503.025	644.780	1.147.805
IC	Dry climate	< 1000		409.412	409.412
IIA	Dry climate	1000-2000	1.324.584	2.320.047	3.644.631
IIC	Dry climate	1000-2000	72.124	960.248	1.032.372
IIIA	Wet climate	2000-3000	29.538	140.840	170.378
IIIC	Wet climate	2000-3000	71.847	48.788	120.635
IVC	Wet climate	3000-4000		47.944	47.944
	Total		2.001.118	4.572.059	6.573.177

Source: Balitklimat (2003)

In NTB province, the distribution type and rainfall patterns have less variation than NTT. Almost all NTB regions categorized as dry-climates zone with annual rainfall <2,000 mm (Table 2), and only 5% of total land have wet-climates (rainfall patterns IIIA and IIIC), located in Central Lombok, West Lombok and East Lombok regencies.

The problem for both NTB and NTT provinces that there are about 71-74% of the land located in hilly (15-25% slopes) and mountainous (>25% slopes) area, indicating that those land may susceptible to erosion. Therefore, conservation agriculture efforts with the selection of a various alternative crops and soil managements need to be prepared to prevent further occurrence of degraded lands.

Agricultural Development Challenges and Directives

Based on the soil characteristics and climate, at least there are two challenges to develop agricultural commodities in NTB and NTT provinces such as water availability, hilly topography and low soils organic matter content. Utilization of ground water (boreholes) and surface water such as ponds, rivers, lakes, and dams become a major source of water for the sustainability of farming system. The selection of commodities and the cropping pattern may an alternative crop management strategies to deal with the long dry months (7-8 months), shallow solum (<50 cm) and rocky (50-65%), as well as the steep slope land (15-30%). For upland crops, corn-green bean crop pattern is better in NTT, while in NTB, the crop pattern may be more varies, such as corn, soybeans, or peanuts.

The main key for food crops development in dry-climates area is water availability. The availability of water throughout the year, encouraging farmers to use the land more intensively with all its limitations, especially to meet the needs of family life. Selection of short-lived economically valuable commodity and accompanied with balanced fertilization (including organic fertilizer and mulching) function as an effort to conserve water and improve soil fertility.

Based on the experience of agriculture development on dry-climates upland, there are some important things that may be used as a lesson for the success and its sustainability, including:

1. Choice of location becomes the initial success of agricultural development activities, including technical and non-technical aspects. The failure and the sustainable activities can occur due to errors in the early stages of site selection.
2. Land resources (land and water), socio-economic and cultural condition, as well as custom farming should be considered in agriculture development.

3. Baseline surveys may needed to determine the condition of land resources, water, and socio-economic culture. In addition, farmer preferences may need to consider in order to obtain information on how the probability of success and the level of adoption of technological innovations are attained.
4. In dry-climates, a survey of potential sources of water are needed to determine the source of water for both surface water (ponds, springs, rivers) or ground water. The availability of water resources is the tipping point in sustainability of agricultural development activities.
5. The irrigation designs and appropriate supplementary irrigation technologies for natural conditions is necessary. However, the irrigation technology should be cheap, efficient, and easily utilized by farmers.
6. Commodities selected should be developed in accordance with the land suitability, appropriate and desired by farmers, as well as having economic value added.
7. Provision of technological innovation in the form of seeds, fertilization (organic and inorganic fertilizers, bio-fertilizers and soil amendment) may be considered to be subsidized depending on the requirements of farmers. Provision of these technological innovations needs to be timely, targeted, appropriate dose of fertilizer application, and easy to implement.
8. Mentoring and intensive training related to technological innovations introduced to accelerate the dissemination and diffusion of these technologies to the user or stakeholder.
9. Coordination and synchronization with the local government needs to be established to sustain the activities.

CONCLUSIONS AND RECOMMENDATIONS

1. Land characteristics in Lombok, Sumba and Timor islands have dry-climate, have medium to high fertility status which characterized by neutral to slightly alkaline pH, medium to high P and K content, high sum of cations, CEC and BS. In contrary, Soil had low organic carbon content, low annual rainfall (<2,000 mm with 7-8 dry months), most of the topography is hilly and mountainous, shallow solum and rocky.
2. Soil chemical and physical properties were closely related to each other, especially between organic matter, texture, BD, total pore space and the availability of water. The higher the C-organic content, the lower the BD, and the higher the total pore space, thereby promoting a more friable soil, more easily cultivated, and higher water holding capability. The higher clay content the higher soil CEC and conversely the higher content of sand, the lower the soil CEC which lead to lower soil ability to hold nutrients and water.
3. Agricultural land management should be focused on the availability of surface water (ponds, boreholes, rivers) sources and increasing organic matter content of soil. Water supply and improving soil quality became tipping point for the agriculture development in dry-climates upland. This may be provided through a conservation agriculture technique.

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