Biophysical characteristics of dry-climate upland and agriculture development challenges in West Nusa Tenggara and East Nusa Tenggara Provinces

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Abstract. West Nusa Tenggara (NTB) and East Nusa Tenggara (NTT) Provinces covered 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. The study aimed to identify biophysical characteristics and propose development challenge of dryland agriculture in NTB and NTT. Biophysical land surveys have been conducted and soil samples have been analyzed for chemical and physical properties. The results showed good fertility status at three islands which was characterized by neutral to basic soil acidity, medium to high P and K total content, high cations content, high CEC and high to very high base saturation. Except for South West Sumba and West Sumba, several observation have indicated acidic pH due to andesitic lava parent material and have >2,000 mm rainfall that lead to high leaching. Soil texture may influence water content where the higher sand portion of soil, the lesser capacity to hold water and nutrients. Fertility status of the three islands is quite good but low in organic carbon content which indicated special attention to improve soil quality. Thus the land management of upland dry-climate area should be focused on surface water availability and conservation agriculture.

1. Introduction

Western part of Indonesia mostly dominated by wet-climate with annual rainfall >2,000 mm per year. From the total about 188.2 million ha land of Indonesia, 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 [1,2].

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 [2,3]. 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 in 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 [1,2]. Besides having dry climates, shallow solum and rocky soil, NTT and NTB provinces also covered by around 71-75% of hilly topography [4]. Therefore, there may 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 [5].

In light of growing concerns over the implications of many conventional agricultural practices, especially the deep tilling of soils, the Food and Agriculture Organization of the United Nations (FAO), among others, has begun to promote a package of soil conserving practices under the banner of ‘conservation agriculture’. Conservation agriculture (CA), defined as minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations, is a more sustainable cultivation system for the future than those presently practiced [6,7]. The CA aims to conserve, improve and make more efficient use of resources through CA-based technologies although it has many tangible and intangible benefits such as reduced cost of production, saving of time, increased yield through timely planting, improved water productivity, adaptation to climate variability, reduced disease and pest incidence through stimulation of biological diversity, reduced environmental footprints and ultimately improvements in soil health [8,9].

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 and analyses the results of the characteristics of soil and climate and obtain the potential and challenges of agricultural development in dry climates of tropical upland and possibility for implementing CA in both NTB and NTT Provinces.

2. Methodology
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 [4] and from climate type and rainfall patterns databases [1]. Data from The Beareu of Statistic [10] was used to verify land use, and the directives national agriculture layout data was used for potential agriculture expansion [4].

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) during FAO project conducted of 2013-2018. 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 Soil Survey Manual [11] and Soil Observation Manual [12]. Soil was classified using Keys to Soil Taxonomy method [13]. 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 P₂O₅ and K₂O content (25% HCl extraction), available P₂O₅ (Bray 1 or Olsen methods), P
retention, exchangeable cations (Ca, Mg, K, and Na), cation exchange capacity (NH₄OAc 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) [14].

3. Results and discussion

3.1. Biophysical characteristic of land resources in NTB and NTT Provinces

The results of the study indicate that the soil type found in NTB and NTT 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 was sediment, followed by volcanic and limestone, producing an Inceptisols (Haplustepts) soil for 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 of NTB and NTT Provinces may lower than in wet-climate area such as in Sumatra and Kalimantan resulting to NTT Province is dominated by shallow solum.

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 [15]. Similarly stated by [3] 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% [16]. 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 [17].

In Sumba Island, the soils mostly has 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. In Timor Island of NTT, the soil pH was 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 lighic properties.

Undisturbed samples collected from NTB and NTT Provinces indicated that bulk density (BD) was >1.0 g cm⁻³, except for Sumba Island. 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.
Table 1. The distribution of soil type based on the parent material at NTB & NTT provinces.

| Parent material | Soil association | NTB (ha) | NTT (ha) | Total (ha) |
|-----------------|------------------|----------|----------|------------|
| Aluvium         | Endoaquepts      | 16,917   | 16,917   | 33,834     |
|                 | Halaquepts       | 39,139   | 39,139   | 78,278     |
|                 | Udifluvents      |          |          |            |
|                 | Udipsamments     | 1,897    | 3,045    | 4,942      |
| **Aluvium Total** |                  | **104,274** | **276,815** | **381,089** |
| Limestone       | Haplusterts      | 7,830    | 32,728   | 40,558     |
|                 | Haplustolls      | 48,416   | 287,580  | 335,996    |
|                 | Ustorthents      | 113,708  | 106,294  | 220,002    |
| **Limestone Total** |                 | **119,180** | **540,310** | **659,490** |
| Reef            | Haplustolls      |          | 268,836  | 268,836    |
|                 | Ustorthents      |          |          |            |
| **Total Reef**  |                  |          | 268,836  | 268,836    |
| Plutonic        | Haplusterts      |          |          |            |
|                 | Haplustolls      |          |          |            |
|                 | Haplustolls      | 28,306   | 28,306   | 56,612     |
| **Plutonic Total** |                 |          |          |            |
| Sediment        | Haplusterts      |          |          |            |
|                 | Haplustolls      |          |          |            |
|                 | Ustorthents      |          |          |            |
| **Sediment Total** |                 |          |          |            |
| Calcareous      | Haplustolls      |          |          |            |
|                 | Ustorthents      |          |          |            |
| **Calcereous sediment total** | |          |          |            |
| Volcanic        | Eutrudepts       |          |          |            |
|                 | Hapludolls       |          |          |            |
|                 | Hapludults       |          |          |            |
| **Volcanic total** |                 |          |          |            |
| **Total**       |                  |          |          |            |

| Parent material | Soil association | NTB (ha) | NTT (ha) | Total (ha) |
|-----------------|------------------|----------|----------|------------|
| Sediment        | Endoaquepts      |          |          |            |
|                 | Hapluduits       |          |          |            |
| **Total**       |                  |          |          |            |
Organic matter can improve soil aggregation, increase the nutrients availability and increase the soil water holding capacity [18]. Soil organic carbon content in the most of samples collected and analysed in Lombok and Timor Islands were classified as very low organic carbon content, but in Sumba organic carbon content indicated relatively higher than other locations. The result of soil analysis indicated that the organic carbon content in the majority of soils (93%) in Timor Island was very low. In Lombok, all soil samples were categorized in very low to low soil organic carbon content while in Sumba 48% was very low to low and was 52% with moderate to high. This indicated that all location of selected sites needs to increase the organic C content of soil. Through this FAO project, by applying conservation agriculture through cover crop with no or minimum tillage and plant rotation may improve soil quality and improves water holding capacity of soil.

**Table 2.** Soil C organic content of Timor (NTT), Lombok (NTB) and Sumba (NTT) islands.

| 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 tends to have a lower soil CEC. Organic-C content affects the soil BD, total pore space, water and microorganisms. Stevenson [19] stated that the addition of organic matter will improve the overall condition of soil physical, biological and chemical properties. According to Rees *et al.* [18], 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 significantly supporting soil productivity for sustainable agricultural systems [20]. In figure 1 appears that the higher organic matter tends to have lower soil bulk density and the higher total pore space.
Figure 1. The relationship amongst soil properties: a. CEC and % of sand; b. CEC and % of clay; c. Available of P and total of P; d. Pore total and bulk density (BD); e. Total of pore and C-organic content; f. C-organic and BD.

3.2. General climate characteristics
Rainfall distribution and climate type in NTB and NTT are presented in table 3 [1]. 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 [21] stated that the loss of soil through erosion has occurred around 11 t ha\textsuperscript{-1} year\textsuperscript{-1} in Kupang and Timor Island.
Table 3. Rainfall distribution and climate type at NTB and NTT provinces.

| Rainfall pattern | Climate type | Rainfall (mm) | NTB (ha) | NTT (ha) | Total (ha) |
|------------------|--------------|---------------|----------|----------|------------|
| IA               | Dry climate  | < 1000        | 503,025  | 644,780  | 1,147,805  |
| IC               | Dry climate  | < 1000        | 409,412  | 409,412  | 818,824    |
| 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   | 95,888     |
| **Total**        |              |               | 2,001,118| 4,572,059| 6,573,177  |

Source: Balitklimat [1].

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 3), and only 5% of total land was in wet-climates condition (rainfall patterns IIIA and IIIC) which were located in Central Lombok, West Lombok and East Lombok regencies. Steward [22] have analyzed adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments using a meta-regression of yields. They found that the relative maize yield performance on conservation agriculture improves with increasing drought severity or exposure to high temperatures. There was an interaction between moisture and heat stress on the relative maize yield performance of conservation agriculture which was modified by the clay content of soil where yields of maize with conservation agriculture may perform less well than those of conventional practice especially on high clay content soils during very wet seasons.

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 [21]. Therefore, conservation agriculture method with the selection of a various alternative crops and soil managements need to be utilized to prevent further occurrence of degraded lands.

3.3 Agricultural development challenges and directives

Based on the soil characteristics and climate, there are at least two challenges to develop agricultural commodities in NTB and NTT provinces such as water availability, hilly topography and low soils organic matter content. The application of conservation agriculture may address the challenges sustainably. Applying cover crop and mulches will improves soil water holding capacity by reducing evaporation, increasing infiltration and soil moisture retention, and a better soil pore system [23,24,25].

It has predicted that in the next decade agriculture will have to produce sustainably more food from less land through more efficient use of natural resources and with minimal impact on the environment in order to meet with growing population [26,27,28]. This will be a significant challenge for government, agricultural scientists, extension personnel, and farmers. Promoting and adopting CA management systems can help meet this complex goal. Furthermore, it has reported that CA increased yields of maize [29,30], reduced labour requirements, improved soil fertility and reduced erosion [31]. However, the empirical evidence is not clear and consistent on many of these points and it nor always clear which of the principles of CA contribute to the desired effects. Some concerns that often faced in the field such as decreased yields often observed with CA, increased labour requirements when herbicides are not used, an important gender shift of the labour burden to women and a lack of mulch due to poor productivity and priority given to feed
Livestock with crop residues. These contradictive evidences need to be tested in the field in order to prove the benefit of CA satisfactorily.

With physiographic condition and the scarcity of water for both NTB and NTT Provinces, application of CA will improve soil condition. The selection of commodities and the cropping pattern may alternative crop management strategies to deal with the long dry months (7-8 months), shallow solum (<50 cm) and rocky land (50-65%), as well as the steep slope land (15-30%). For upland crops, maize-green bean crop pattern may be better in NTT. In NTB, the crop pattern may be more varies with maize, soybeans, or peanuts. Based on the experience of agriculture development on upland dry-climates, 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 be occurred due to misplace 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 dryland agriculture development.
3. Baseline surveys may be needed to determine the condition of land resources, water, and socioeconomic 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, surveys of potential sources of water are needed to determine the source of water for both surface water (ponds, springs, rivers) and 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 users or stakeholder.
9. Coordination and synchronization with the local government needs to be established to sustain the activities.

4. Conclusions
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 the contrary, soil had low organic carbon content, low annual rainfall (<2,000 mm with 7-8 dry months), most of the topography pattern was hilly and mountainous, shallow solum and rocky land. The higher C-organic content, the lower soil bulk density, and the higher 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. Based on the land characteristic of NTB and NTT Provinces, agricultural land management should be focused on improving soil quality and increasing organic matter content of soil. Water supply and improving soil quality became tipping point for the agriculture development in upland dry-climates. This may be provided through a conservation agriculture technique.
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