Minimizing the impact of climate change through the determination of land and plant technology needs based on the agroecological zone on food crops in Boyolali District of Central Java, Indonesia

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Abstract. The agroecological zone (AEZ) is a land potential information system for land use planning and commodity development. AEZ contains information on landforms, elevation, topography, soil characteristics, temperature, etc. which is useful for determining the suitability of land and commodities. This study aims to determine the technology requirement based on the limiting factors found in each land unit. The methods of determination of land suitability and technology requirement were carried out using the FAO standard land evaluation program, by matching land characteristics with plant growth needs. Through the application of recommendation technology that suitable for land capability, the cultivation system becomes more adaptive to the environment, so that the possible negative impact of climate change can be minimized. The limiting factors found as constraints to the development of food crops in the Boyolali District include (a) temperature conditions, (b) rooting conditions, (c) nutrient retentions, (d) erosion hazard, (e) land preparation, and (f) flooding hazard. Based on existing limiting factors, land management should be focused on (a) using adaptive varieties to local temperatures; (b) providing organic fertilizer to improve soil drainage, organic C and CEC soil; (c) lime and soil ameliorant application to increase base saturation, deep and reverse soil treatment to increase CEC; (d) conservation-oriented planting system and (e) eradication of rocks with minimum tillage.

1. Introduction
The results of agricultural research have reported that optimum agricultural production can be achieved if the technology applied is following the type and potential of the region. To develop recommendation technology, information is needed about the potential and condition of land resources, and the surrounding environment is needed. Agroecological zone (AEZ) is a concept of simplifying and grouping diverse agroecosystems in the form of classification and information that is more applicable [1]. According to FAO [2], the AEZ is a unified map of land resources determined based on climate, landform, soil and land cover, which has a specific range of potential and inhibitors for certain land uses. Therefore, through the AEZ approach, land potential utilization can be identified quickly and precisely.
AEZ information systems also make it easier to identify the needs of land management technology for the development of a commodity. Adhimhardja et al. [3] said that one of the applicative benefits that can be taken from AEZ is an assessment of land degradation and land management optimization models. By using the land evaluation program, several food crop commodities can be identified as the need for land management technology based on the requirements of plant growth requirements with the existing limiting factor. AEZ information can also be used as a tool to assess land potential as a basis for developing land-use planning and agricultural commodity development so that it can indirectly minimize the effects of climate change that occur.

Boyolali District is one of the centers of food crop development in Central Java, with an area of rice fields around 45,779 hectares [4]. Some potential food crop commodities and are widely developed in Boyolali District include irrigated lowland rice, rainfed lowland rice, upland rice, maize, sorghum, cassava, taro, soybeans, peanuts, green beans, cowpea. Judging from the potential of land resources, Boyolali District has very varied characteristics both in terms of potential advantages and limitations [5]. Therefore, for the purpose of developing food crop commodities and in the context of optimizing the use of potential land resources and their management, it is important to identify the technological needs of land management in food crops. Through the application of recommendation technology that is appropriate to the capabilities of the land, it is hoped that crop production can be optimized while being able to minimize the impact of climate change.

2. Methods

The study of identifying the need for land and plant management technologies was carried out specifically for food crops in Boyolali District, Central Java by using an AEZ database at the scale of 1:50,000. AEZ determination is done by using a base map and radar image analysis, which is classified in the land unit map. Identification of soil characteristics is carried out through observational surveys and soil sampling in each variation of land units. Soil samples were analyzed for all properties related to plant growth requirements.

Identification of land management technology needs in food crops is carried out using the FAO standard land evaluation program through aligning and matching data on the characteristics and quality of the land with data on optimal plant growth requirements. The system of land management technology needs analysis is carried out based on the types of plant growth limiting factors that can be identified by referring to the land suitability evaluation guidelines [2][6][7][8].

Several types of food crops that have been identified for their technological needs include irrigation lowland rice, rainfed lowland rice, upland rice, maize, sorghum, wheat, cassava, sweet potatoes, taro, soybeans, peanuts, green beans, cowpea.

3. Results and discussion

3.1. Land resource characteristics

Based on the results of the characterization of AEZ (Table 1), Boyolali District was identified as having an area of 108,566.29 hectares with 33 land units. Land unit is a plot of land or area that has the same or similar land elements. The land elements consist of: (a) landform, (b) main material/lithology; and (c) the shape of the area and slopes [2][10][11]. Based on land survey and land evaluation guidelines [11][12] in Table 1 it appears that Boyolali District is dominated by lands with volcanic formations consisting of volcanic plain, lava flow, subresen lava flow, small cone, volcanic slope, and crater. The volcanic area which covers an area of 67.5% is a landform with andesite, basalt, and tuff parent material, about 25.3% spread over lowland to medium plains, so it is a potential area for food crops development. The second-largest volcanic area is an area with subresen lava flow landform of about 21.3% of the area.

Based on the AEZ database, Boyolali District is dominated by areas with a rather flat to undulating topography with slope classes of 1-3% and 8-15%, with an area of around 65.549% of the total area of the district. The zone with a rather flat topography is a potential area for the development
of annual food crops. Whereas in zones with undulating topography, the development of annual agricultural crop commodities should have been combined with about 25% of tree crops.

Table 1. Landform distribution in Boyolali District [5][10].

| No. | Landform                | Parent Material          | Slope (%) | Area (Ha) |
|-----|-------------------------|--------------------------|-----------|-----------|
| 1   | Flow path               | Clay deposits            | (1-3)     | 2,390.64  |
| 2   | Flow path               | Clay deposits            | (3-8)     | 398.04    |
| 3   | Flow path               | Clay deposits            | (8-15)    | 92.14     |
| 4   | Coluvial land           | Clay deposits            | (1-3)     | 5,302.31  |
| 5   | Coluvial land           | Clay deposits            | (3-8)     | 187.08    |
| 6   | Ridges of karst plains  | Limestone                | (3-8)     | 393.99    |
| 7   | Ridges of karst plains  | Limestone                | (8-15)    | 532.12    |
| 8   | Tectonic choppy plains  | Claystone & sandstone    | (1-3)     | 294.84    |
| 9   | Tectonic choppy plains  | Claystone & sandstone    | (3-8)     | 925.29    |
| 10  | Tectonic choppy plains  | Claystone & sandstone    | (3-8)     | 73.11     |
| 11  | Tectonic choppy plains  | Claystone & sandstone    | (3-8)     | 1,862.37  |
| 12  | Tectonic hill           | Limy clay stone & sandstone | (15-25) | 15,505.04 |
| 13  | Tectonic hill           | Limy clay stone & sandstone | (25-40) | 6,419.94  |
| 14  | Crater                  | Andesite                 | (>40)     | 130.81    |
| 15  | Upper volcanic slope    | Andesite & basalt        | (25-40)   | 1,318.11  |
| 16  | Upper volcanic slope    | Andesite & basalt        | (>40)     | 5,358.48  |
| 17  | Midle volcanic slope    | Andesite & basalt        | (8-15)    | 1,804.01  |
| 18  | Midle volcanic slope    | Andesite & basalt        | (8-15)    | 5,114.38  |
| 19  | Midle volcanic slope    | Andesite & basalt        | (25-40)   | 4,150.91  |
| 20  | Bottom volcanic slope   | Andesite                 | (8-15)    | 1,551.79  |
| 21  | Resen lava flow         | Andesite & basalt        | (25-40)   | 247.61    |
| 22  | Sub resen lava flow     | Andesite, basalt & tuff  | (1-3)     | 6,394.41  |
| 23  | Sub resen lava flow     | Andesite, basalt & tuff  | (3-8)     | 682.40    |
| 24  | Sub resen lava flow     | Andesite, basalt & tuff  | (3-8)     | 800.31    |
| 25  | Sub resen lava flow     | Andesite, basalt & tuff  | (8-15)    | 11,294.27 |
| 26  | Sub resen lava flow     | Andesite, basalt & tuff  | (8-15)    | 3,190.99  |
| 27  | Sub resen lava flow     | Andesite, basalt & tuff  | (15-25)   | 517.38    |
| 28  | Lava flow               | Andesite & basalt        | (>40)     | 488.66    |
| 29  | Volcanic plain          | Andesite                 | (1-3)     | 7,395.69  |
| 30  | Volcanic plain          | Andesite                 | (3-8)     | 15,250.38 |
| 31  | Volcanic plain          | Andesite                 | (8-15)    | 4,864.75  |
| 32  | Small cone              | Andesite                 | (15-25)   | 735.91    |
| 33  | Small cone              | Andesite                 | (25-40)   | 1,990.02  |

The land characteristic element that has a very important role in determining the suitability class of agricultural commodities is soil texture and drainage (Table 2).

Table 2. Soil texture and drainage distribution in Boyolali District [5][13].

| No. | Texture Class | Area (ha) | (%) | No. | Drainage          | Area (ha) | (%) |
|-----|--------------|-----------|-----|-----|-------------------|-----------|-----|
| 1   | Silt         | 488.66    | 0.46| 1   | Excessively drained | 130.81    | 0.12|
| 2   | Silty loam   | 11,075.11 | 10.45| 2   | Somewhat excessively drained | 488.66    | 0.45|
| 3   | Sandy loam   | 20,364.76 | 19.22| 3   | Well drained       | 34,226.28 | 31.79|
| 4   | Silty clay   | 1,804.01  | 1.70| 4   | Moderately well-drained | 36,161.28 | 33.59|
| 5   | Sandy clay   | 398.04    | 0.38| 5   | Somewhat poorly drained | 13,684.91 | 12.71|
| 6   | Clay         | 66,542.69 | 62.79| 6   | Poorly drained     | 22,965.80 | 21.33|
| 7   | Silty clay   | 5,302.31  | 5.00|     |                   |           |     |
Soil texture has a role in determining the condition of the tillage layer to its friability and also in determining the class of soil drainage. The level of soil drainage is also strongly influenced by the level of slope. Table 2 shows that most of the area in Boyolali is dominated by clay texture which covers about 62.79%. The condition is usually one of the reasons that soil drainage is in a somewhat poorly drained to poorly drained class. Therefore, soil texture and drainage are also the main determinants of soil type. Based on the distribution of soil types (Table 3), Boyolali District is dominated by Latosol, Kambisol (Inceptisols), and Andosol (Andisols). The proportion of other soil types are Mediterranean, Regosol, Grumusol, Alluvial, and Renzina.

Table 3. Distribution of soil types in Boyolali District [14][15].

| No. | National Soil Classification | Area (ha) (%) | USDA Soil Taxonomy | Area (ha) (%) |
|-----|------------------------------|---------------|--------------------|---------------|
| 1   | Regosol                      | 5,977.95 5.56 | Entisols           | 11,280.26 10.50 |
| 2   | Aluvial                      | 5,302.31 4.94 | Andisols           | 14,168.81 13.19 |
| 3   | Andosol                      | 14,168.81 13.19 | Andisols           | 14,168.81 13.19 |
| 4   | Grumusol                     | 5,768.71 5.37 | Vertisols          | 5,768.71 5.37 |
| 5   | Kambisol                     | 15,903.08 14.80 | Inceptisols       | 65,920.74 61.36 |
| 6   | Latosol                      | 50,017.66 46.56 | Alfisols          | 10,107.67 9.41 |
| 7   | Mediterranean                | 10,107.67 9.41 | Mollisols          | 181.95 0.17 |
| 8   | Renzina                      | 181.95 0.17 |                    | 181.95 0.17 |

3.2. The need for land management technology and alternative recommendations based on the limiting factors for plant growth

The utilization of land resources for the development of a commodity can be pursued through two main ways, namely (a) selecting locations that have the quality and characteristics of the land following the requirements for optimal growth of commodity to be developed, and (b) selecting an appropriate commodity (adaptive) with the quality and characteristics of the land to be used. Based on the land characteristics and some limiting factors for the development of food crop commodities (Table 4), several land management technology needs and alternative recommendations can be identified, as follows:

3.2.1. The technology of manipulating the limiting factors in temperature conditions. Temperature condition in certain places is a minor limiting factor in the development of almost all food crop commodities in Boyolali District. Food crops that have the widest temperature suitability include rice, maize, cassava, taro, and peanuts. In several regions, sweet potato plants cannot produce optimally because the temperature is too high or too low from the optimal requirements. So that if the development will still be carried out in the area, one of the technological alternatives can be recommended through the selection of specific varieties for the specific location. Besides, the treatment of micro-temperature manipulation through the planting of shade plants and screen houses can also be recommended for certain crops. Technology to minimize the temperature limiting factor can also be done by adjusting the planting time in the months where the air temperature is relatively ideal for plant growth needs. For example, to grow garlic, it should be estimated at the time of the formation of tubers at the age of 50 days after planting coinciding with the coldest air temperatures, which usually occurs around July [16].

3.2.2. Land management technology to improve the rooting condition. Rainfed lowland rice plants are food commodities that have the most extensive limiting areas because of the suboptimal rooting media due to clay or sandy soil texture, which cause soil drainage (poorly or excessively drained). Besides, the amount of coarse material in the tillage or effective depth is also a cause of the limiting factor in rainfed lowland rice plants. Soil conditions with the limiting factor of rooting condition for lowland rice plants are found inland units 2,3,5,6,8,9,10,11,12,18,24,27,30,32, which are spread almost in all
While taro plants have a distribution area with the lowest limiting factor in the rooting condition media compared to others, namely on land units 4,18,22,29,30. Several alternative technologies that can be recommended for this area include the provision of high organic fertilizer inputs, so the soil nutrients and water retention will be better. In addition, deep and reversible tillage systems can also be recommended for sandy textured areas like this, because in this way fine soil particles leached into the lower layers can be lifted again so that in addition to increasing supply capacity leached nutrients.

3.2.3. **Land management technology to improve nutrient retention conditions.** Based on the characteristics of nutrient uptake which are interpreted from cation exchange capacity (CEC) data, base saturation, soil acidity (pH-H₂O), and soil organic C content, most food crop commodities have nutrient absorption limiting factors due to soil pH factors <6, relatively low soil organic C content (<1%), and partly with CEC conditions <16 [7]. Food crops from cereals and legumes are types of plants that have limiting factors for nutrient uptake caused by base saturation <60 and soil pH <6. Rainfed rice, maize, and peanuts have the most widespread distribution of nutrient absorption factors in land units 1,2,3,5,6,9,17,18,22,23,24,27,29,31,32,33, which are distributed in Andong, Simo, Nogosari, Sambi, Ngemplak, Sawit, Banyudono, Cepogo and Musuk Sub-Districts. Several technologies recommended to improve these nutrient retention problems include (1) continuous organic fertilizer application (as long as possible for every season) for excessively drained soils, which at the same time can provide the benefit of increasing organic C content and soil CEC, (2) applying lime to decrease soil acidity where soil pH is <6, and (3) deep and reversible tillage systems for excessively drained areas, so that fine soil particles (silt and clay) washed down can be raised again so that it is useful to increase CEC.

3.2.4. **Land management technology to control erosion hazards.** Some agricultural commodities which have development limiting areas due to erosion hazard factors are generally caused by hilly to mountainous topography with slopes >25% and have not done much on land conservation efforts such as terracing so that for the development of seasonal commodities such as food crops, there is a great chance to be the cause high erosion. Almost all food crop commodities have a limiting factor in erosion hazard except lowland rice. In general, food crops in Boyolali have erosion limiting factors in land units 3,12,13,18,19,27,31,32,33 which are the most widespread in Juwangi, Kemusu, Wonosegoro, Karanggede, Klego, Simo, Sambi, Andong, Ampel, Cepogo, Selo and Musuk. Conservation-oriented land management is a technological need that must be recommended in several areas that have limiting factors of erosion hazard because erosion hazard in these areas is quite high when used for the development of almost all food crops. Therefore, some conservation technologies that can be recommended for this area are making terraces, planting with contour cropping with planting grass for terraces reinforcement, alley cropping systems, grass strips, and making canals and flow reservoirs [7][8].

3.2.5. **Land preparation technology.** The main limiting factor in preparing land is the percentage of rock material and rock outcrops. In Boyolali District, there were no problems in terms of land preparation except for lowland rice plants which encountered a slight problem of rock material in the land unit 12, which is spread in Juwangi, Kemusu, Wonosegoro, Karanggede, Klego, and Simo. Land management problems that occur due to the difficulty of land preparation can be reached by efforts to remove or clear land from the rocks. Other alternative technologies that can be recommended are through a minimum tillage system (such as a hole digging system) and selection of commodity types that do not need to be planted tightly, especially for tuber crops such as potatoes. Preferably, the minimum tillage system with a dug hole is still accompanied by the provision of adequate organic fertilizer.
3.2.6. Management technology for limiting water availability due to flooding and inundation. Based on the AEZ database in Boyolali District, only 2 land units were identified that had flood or inundation hazard limiting factors, namely inland unit with Alluvial Eutrik soil types, which is spread in Wonosegoro, Kemusu, Klego, and Karanggede Sub-District, and land units with the type of soil Latosol Gleik, which is spread in Sambi and Ngemplak Sub-District. In this land unit, 3 crop commodities have limiting factors by the flooding or inundation hazard, namely soybean, peanut, mung bean, and cowpea, each of which reaches a marginal suitability class (S3). Whereas peanut plants are not suitable (N).

The problem of limiting factors in the availability of water that occurs in parts of Juwangi, Wonosegoro, Karanggede, Kemusu, Mojosongo, Teras, Banyudono, Ngemplak has an uneven distribution of rainfall throughout the year wherein certain months it has rainfall > 200 mm per month, so make less optimal growth of soybean, peanut, mung bean, and cowpea plants. Therefore, one alternative technology that can be recommended is through improved planting schedules by considering rainfall patterns, flooding or inundation that occur in previous seasons, which are sought at the time of flowering, the formation and filling of pods without excess water or when rainfall starts to decline.

Table 4. Distribution of factors limiting the growth of some food crops in Boyolali District.

| Commodity       | Limitation factor and land unit | Temperature condition | Rooting condition | Nutrient retention | Erosion hazard | Land prepare | Flooded & inundation |
|-----------------|---------------------------------|-----------------------|-------------------|-------------------|----------------|--------------|---------------------|
| Irrigated lowland rice | 17,18                           | 2,4,9,18,22,23,26,27,29,30 | 3,22,23,24,27,29,31,32,33 | 12,27,33         | 4              | 12           |
| Rainfed lowland rice  | 17,18                           | 2,3,5,6,8,9,10,11,12,18,24,27,30,32 | 3,17,18,22,23,24,27,29,31,32,33 | 12,13,27         | 12             |
| Upland rice        | 17,18                           | 2,4,9,18,22,23,26,29,30 | 1,2,5,9,17,18,24,29,31,32,33 | 3,12,13,27,32,33 | 33             |
| Maize             | 17,18                           | 2,4,9,18,22,23,26,29,30 | 3,17,18,22,23,24,27,29,31,32,33 | 3,12,19,27,33    |                |
| Sorghum           | 2,4,9,18,22,23,26,29,30         | 3,17,18,22,24,27,29,31,32,33 | 3,12,19,27,33    |                  |
| Casava            | 19                              | 1–6,8–12,18,22–27,29–33 | 2,4,5,17,18,25,26 | 12,18,19,27,       |
| Sweet potato      | 1,2,3,5,6,8–11,18,19,25         | 2,4,9,18,22,23,26,29,30 | 18,24,31,32       | 3,12,18,19,27,31,32,33 |
| Taro              | 17,18                           | 4,18,22,23,29,30       | 1,2,4,5,8,9,17,24,25,26,29,31,32,33 | 3,6,10,11,17,18,24,25,26,29,31,32,33 | 18,24,26,31       |
| Soybean           | 1,2,3,5,6,8–11,19,25            | 2,4,9,18,22,23,26,29,30 | 1,2,5,17,18,24,25,29,31,32,33 | 3,12,27,32,33    | 4,23           |
| Peanut            | 24,30,32                        | 3,6,8,10,11,22,24,29,30,32 | 1,2,3,5,6,9,17,18,24,25,26,29,31,32,33 | 3,12,19,27,32,33 | 1,6,8,10,11     |
| Green bean        | 2,3,5,6,8–11,25                 | 2,4,9,18,22,23,26,29,30 | 3,5,17,18,22,24,29,30,32,33 | 12,19,27,30      | 4,23           |
| Mungbean          | 1,2,3,5,6,8–11,19,25            | 2,4,9,18,22,23,26,9,30,32,33 | 3,6,17,18,22,23,25,26,29,31,32,33 | 3,12,19,27,33    | 4,23           |

4. Conclusion
Land management technology in food crops can be identified by utilizing an AEZ database that is matched with plant growth requirements using land evaluation programs. Dominant land limiting factors for food crop development in Boyolali District based on priority scale include (a) temperature conditions (b) rooting conditions, (c) nutrient retention conditions, (d) erosion hazard level, (e) difficulty in land preparation, (f) the risk of excess water rain (flooding) and inundation.
Some alternative land management technologies needed for the development of food crops include (a) selecting commodities that are adaptive to local temperatures or selecting locations that have the quality and characteristics of the land following the requirements for optimal growth of commodity to be developed, (b) improvement of soil drainage conditions by providing organic fertilizer and soil amelioration, (c) liming, application of high and continuous organic fertilizer, and deep and reversible tillage, (d) conservation cropping systems through terraces, contour cropping, strips and alley cropping, the manufacture of sealing channels and surface flow retainers, (e) eradication of rocks and minimum tillage, and (f) adjusting cropping patterns with due regard to the distribution of rain and inundation or flood cycles.

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Ridha Nurlaily (RN) as the first author contributed to conducting research, analyzing data, preparing papers, and involving herself in all the process of preparing papers for the 5th International Conference of Climate Change (5th ICCC 2020) as the main contributor under the guidance of the second author. Samijan (S) as the second author contributed and was fully responsible for the planning and implementation of research, data analysis, and the preparation of papers until the paper was received and presented at the 5th International Conference of Climate Change (5th ICCC 2020) and published on the journal or proceeding, as the main contributor and supervisor of the first author.