Applied Geo-Eye Imagery and GIS for Estimating Crop Production Based On Land Suitability in Karangasem Regency, Bali

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Abstract. Farming practices are vital to agrarian countries like Indonesia. Over the years, regional development process, coupled with lack of information on agricultural production, has induced human interventions on land that markedly convert agricultural into non-agricultural land use. Therefore, estimating crop production becomes necessary for a deeper understanding on the farming potential of a region. The study was conducted in various physical environments in Karangasem Regency, Bali. It aimed to 1) estimate both crop production and productivity using land suitability approach; 2) calculate the crop production and productivity; and 3) map the type of cropping pattern and schedule in the study area. Crop production was estimated with remote sensing and Geographic Information System (GIS) techniques and based on land suitability for rice, maize, and cassava production. The results show that remote sensing and GIS are essential in the estimation of crop production and productivity that employs land suitability approach and matching method. The estimated productions of rice, maize, and cassava are 540,173.840 kg/year, 1,843,857.202 kg/year, and 903,416.517 kg/year, respectively. In addition, the cropping pattern in Karangasem Regency varies between land suitability units, as determined by subak irrigation system, weather variation, and the economic condition of farmers.

Keywords: Agriculture, Crop Production, Land Suitability, Remote Sensing, GIS
1. Introduction
As an agrarian country, Indonesia depends largely on agricultural sector. Developing countries are typically defined with a vast agricultural sector in which, statistically, 75% of the populations engage in agriculture, more than 50% of the national incomes also originate from the same sector, and almost all of the exports include farming materials [10]. However, the existing agricultural potential lacks the inducement for the Indonesians to develop this sector. The paucity of information on crop production and productivity in every region creates limited knowledge on the beneficial outputs of farming activities. Furthermore, as the region develops, agricultural to non-agricultural land use conversion becomes preferable. Therefore, the estimation of crop production is important for describing the significance of farming potential in a region.

Bali, part of Sunda Kecil Islands, is 153 km in length, 112 km in width, and approximately 3.2 km from Java Island. It lies between 8°25′23″ S and 115°14′55″ E and, thereby, has tropical climate. Even though Bali is famous of its tourism sector, the agricultural practices also contribute significantly to its development. Food availability in Bali is determined, for instance, by the agricultural production level. Meanwhile, the food demand is affected by the increasing trend of population growth over the years. Accordingly, the need for access to information on the accurate crop production estimates grows rapidly. Applying remote sensing and Geographic Information System makes the estimations faster and more accurate than conducting terrestrial surveys. The estimation of crop productivity in Karangasem Regency, Bali aimed to estimate the crop production and productivity using land suitability approach in the study area, to calculate the crop production and productivity in the study area, and to understand the type of cropping pattern and schedule in the study area. Crop production was estimated with remote sensing and Geographic Information System (GIS) techniques and based on land suitability for rice, maize, and cassava production. The results show that remote sensing and GIS are essential in the estimation of crop production and productivity that employs land suitability approach and matching method.

2. Materials and Methods
2.1. Data
The study employed land suitability approach with matching method to estimate the crop production and productivity in Karangasem Regency. The field surveys used GPS, soil test kit, and abney level. Meanwhile, the analysis was conducted on a set of data, viz. GeoEye satellite image in 2014, the land use maps of Karangasem Regency (scale 1:25,000), the Reconnaissance Soil Map of Bali Province (scale 1:250,000), rainfall data, and the table of land suitability for crop productions. The estimation of crop production in this study was based on land units, with various parameters of land suitability, i.e. soil, climate, slope, rainfall, and agricultural land (paddy field and dryland), which were ‘matched’ with the table of land suitability for every commodity. The study obtained information on agricultural and non-agricultural land use from GeoEye satellite image because of its high spatial resolution. The image also accentuated certain objects that were useful for extracting the physical characteristics of land, such as slope, soil feature, and water potential, and thereby simplified the identification process.

2.2. Methods
2.2.1 Study Area Selection. Karangasem Regency was selected because it represents regions that depend on vast agricultural areas with diverse cropping patterns and commodities. It also has extensive natural resource potentials for agriculture, fishery and marine sector, and mining. Its economic development is mainly supported by farming activities, as shown by the agricultural share of the Gross Regional Domestic Product (GRDP) in 2009, i.e. 28.96%. The major dryland farming in the study area is due to the diverse topography including an old volcano (Mt. Agung) on one of its side. The estimation of crop production, as sampled according to land units, considered the physical environments of the study area. The development of cropping calendar significantly promotes the process of maximizing crop productivity especially in the presence of diverse cropping patterns for various types of farming commodities in Karangasem Regency.
2.2.2 Pre-field Preparation

2.2.2.1 GeoEye Image Correction. The 2014 GeoEye image of the study area shows that the landform change in the corresponding year was not significant. The image was corrected geometrically, i.e. restoring the position of pixels in a way that the transformed digital image can visualize the sensor-recorded objects on the Earth's surface [3]. Geometric correction can be conducted in two ways: 1) by referring to data from spacecraft and knowledge on internal distortion; and 2) by conducting Ground Control Point (GCP)-based transformation [3]. The geometric correction in this study used image-to-image registration method, i.e. correcting one image with other geo-referenced satellite images in the same area. The coordinates from the same area were then adopted based on the GCPs as the coordinate reference of the study area. GeoEye satellite image have high spatial resolution so its can obtained information on agricultural and non-agricultural land use. The satellite image was identified using visual interpretation, i.e. on-screen digitation on the corrected satellite image to classify the cropland such as rice, maize, and cassava. The result of identified image using visual interpretation were verified by comparing with field survey data.

2.2.2.2 Agricultural and Non-agricultural Land Classification. Agricultural land was one of the main factors in the crop estimation process that served as the object of this study. It represented the extent of the cultivated area in the regency. It was identified using visual interpretation, i.e. on-screen digitation on the corrected satellite image. The study used on-screen digitation because visual delineation, using elements of interpretation, offers a good accuracy. The object identification provided the distribution of agricultural and non-agricultural land in the study area.

2.2.2.3 Agro-ecosystem. The regional potential for the development of agricultural and forest commodities is essentially determined by the nature of the physical environments, which includes climate, soil, topography, hydrology, and several conditions for crop growth [7]. Meanwhile, land suitability is shaped by several parameters such as slope, rainfall intensity, soil feature, and water potential. Slope defines the distribution of water in an area and, at the same time, water availability becomes the main factor in determining farming commodities and cropping patterns. Slope was extracted from contour data presented in the topographical map (RBI) and, then, used for providing information on terrain units. Meanwhile, the characteristics of rainfall determine the corresponding crop types. Rainfall data in the last 10 years were interpolated in order to obtain the rainfall intensity in the study area. The interpolated rainfall also provided the relative classification of rainfall intensity and its interval, as compared to other regions with similar rainfall intensity. In addition, slope profile was extracted from the soil map of Bali (scale 1:25,000). This map was processed to increase its details, using the slope map, i.e. by classifying the slope and associating it with soil type. As a determinant of land suitability, water potential was analyzed based on the presence of river. The physical parameters like landform, slope, soil feature, and water potential were combined to shape the characteristics of terrain units. Afterwards, these units were also merged with agricultural land use data in order to divide the study area into land units that were used as sampling reference during field survey. In addition to land units, the study also created agro-ecosystem units as the representations of existing agricultural ecosystem in which productivity is defined as a balanced presence of soil, nutrient, sunlight, humidity, and organism that jointly creates a healthy cropping environment and sustainable yield [1]. Agro-ecosystem units combined a set of data on land units, which had been matched with the table of land suitability for crops, and agricultural land use. This matching method was used for land evaluation, i.e. comparing the criteria of land suitability and the exact data on land quality [4]. Meanwhile, land suitability assessment is defining a specific land based on its existing qualities and characteristics that shape certain conditions for crop growth; in other words, the evaluated land has specific suitability for certain crops [9]. The study also conducted a field check for agro-ecosystem units.
2.2.2.4 Field Survey. The field survey was conducted in order to acquire primary data and check the results of pre-field data processing. The results of the field survey were used for checking the accuracy of land unit approach and sampling on land units indicated that every land unit was represented by several field samples that met the objective of the study and the extent of land units. The wider the land units, the more the samples. Field samples were selected effectively in order to represent the real condition. Field survey was conducted with direct observation and interview. Direct observation aimed to understand the types of commodity, while interview aimed to find more information on cropping pattern, crop yield, and agricultural productivity.

2.2.2.5 Post-field Analysis. Post-field activities focused on field data analysis in order to map the crop production estimates. The calculating crop production. Field survey aimed to acquire a set of data on commodity, productivity, and cropping pattern as well as to evaluate the pre-field image interpretation of agricultural area. Purposive random calculation of the estimation mainly attempted to acquire information on agricultural production in Karangasem Regency. The estimation process included the multiplication of every type of commodity in every identified land unit by agricultural productivity per area. It also involved the cropping pattern in the study area in determining the annual crop production. The estimation produced the annual production of every commodity in Karangasem Regency.

3. Result, Analysis, and Discussion

3.1 Pre-field.

The first step of the study was pre-field activities, i.e. creating rainfall map, drainage map, soil map, and land suitability maps for maize, rice, and cassava production. Afterwards, these base maps were used for creating field survey maps, namely slope map, land use map, tentative map of agro-ecosystem, and map of sampling locations. Slope map is defined as the change in elevation over a given horizontal distance between two points. It transformed the contour data presented in the topographical map (RBI scale 1:25,000) into DEM and defined the slope based on the classification of [12] as shown in Figure 1. slope determines land suitability in a way that a steep area has different water availability, as well as different land suitability, from a gently sloping area. However, in Karangasem Regency, slope is not an issue in land suitability due to the presence of terraces as land modification.

The land use in Karangasem Regency is relatively homogeneous, as shown in Figure 2., i.e. dryland and dry agricultural area. Land suitability mapping for estimating crop production refers to two types of land use, namely agricultural and non-agricultural land use shown in Figure 3. In this case, remote sensing provided satellite images, while the elements of interpretation provided a means of acquiring data on the aforementioned land use types from satellite images. Agricultural land appears as an area with low vegetation and, thereby, with smooth texture, as compared with other vegetation appearances. Analysis of the application of remote sensing for estimating crop production refers to agricultural land use only because the cultivation of rice, maize, and cassava, as the focus of the study, presents in agricultural land use. The study assumed that the wider the agricultural land, the higher the crop production.

Soil characteristics presented in land suitability map includes soil surface texture, soil permeability, pH, and soil fertility. Four of these characteristics determine the suitability of agricultural land. As shown in Figure 4. based on the derivative information of soil maps, the soil types in the study area are grayish-brown alluvial, brown latosol, Litosols, regosol with humus presence, brown regosol, yellowish-brown regosol, grayish-brown regosol, and gray regosol. Regosals, mainly found in Karangasem Regency, are young soils that show no or little soil horizon development. They are characterized by sandy texture, normal pH, and medium fertility, and originated from pyroclastic materials; hence, their spatial associations with slopes of young volcanoes. Soil texture and permeability are the two intercorrelated soil properties that determine water availability for crop growth. Texture defines the amount of stored and transmitted water. Therefore, the more coarse or silt the texture, the higher the infiltration capacity. On the contrary, the
finer or more clay-sized particles the soil has, the lower the infiltration capacity. Water infiltration capacity determines the rate of water movement in a soil (permeability); therefore, the slower the water transfer rate, the more the land suitability for crop production. Soil pH represents the acidity of a soil. A ‘good’ soil has normal pH (5-7); in other words, the lower the pH, the lower the land suitability for crop production. Soil fertility is determined by the nutrient contents of a soil. The more the nutrient contents, the more fertile the soil. Furthermore, the more fertile the soil, the better the crop growth.

Rainfall intensity in the study area is categorized into 7 classes, ranging from the lowest intensity, i.e. 1,300 mm/year, to the highest intensity, i.e. 3,300 mm/year. It indirectly represents the water availability of an area, as stored either in surface water or in groundwater. Even though maize and cassava require less water than rice, the productions of these three commodities imply that a better
land suitability for crops is associated with higher rainfall intensity, and vice versa. The implication refers to the relationship between higher rainfall intensity and better drainage. However, such conclusion needs to consider the role of slope and soil profile as well. As shown in Figure 5, the drainage condition in the study area is divided into 3 classes, namely good, fair, and poor drainage. Poor drainage is commonly found in steep slope with sandy soil, while good drainage is typically found in a gently sloping to flat area.
Land suitability is determined by several parameters, namely rainfall, drainage, temperature, effective soil depth, soil pH, and slope. The combination of these parameters lead to different land suitability, viz. highly suitable (S1), suitable (S2), and not suitable (N) (Hardjowigeno and Widiatmaka, 2011). In addition, land suitability for every crop is different. As shown in Figure 6, 7, and 8, the conditions for rice growth compose the criteria in every class of land suitability: a highly suitable land for rice production (S1) has rainfall intensity >1,500 mm/year, poorly drained, effective soil depth >50, pH >5.5-7, and slope <3%; suitable land (S2) has rainfall intensity 1,200-1,500 mm/year, poorly drained, effective soil depth >40-50, pH >7-8 or 5.5-<6, and slope 3-8%; and not suitable land (N) has low rainfall intensity (<800 mm/year), excessively drained, effective soil depth 20-25, and slope >15-25%.

Meanwhile, the land suitability for maize growth is as follows: highly suitable (S1) comprises rainfall intensity >1,200 mm/year, poorly to fairly drained, effective soil depth >60, pH 6-7, and slope <3%; suitable (S2) comprises rainfall intensity between 900-1,200 mm/year, imperfectly drained, effective soil depth >40-60, pH >7-7.5 or 5.5-<6, and slope 3-8%; and not suitable (N) comprises low rainfall intensity, no drainage, effective soil depth 20-24, pH >8-8.5 or 4-4.5, and slope >15-24%. Land suitability data for the three commodities are presented in the agro-ecosystem map, which consists of 18 types of land suitability for all commodities, as shown in Figure 9. Based on this agro-ecosystem map, 22 samples were selected using random sampling technique.

3.2 Field Survey
Field survey included physical measurements and interviews. The physical measurements used abney level for slope measurement and soil test kit for soil pH measurement. Field survey was conducted because not every parameter of land suitability can be extracted from satellite images or secondary data during pre-field activities. Besides, field survey provides a means to check the accuracy of pre-field interpretation results like slope. Interviews were conducted to farmers who managed the sampled
agricultural land. These interviews used questionnaires for acquiring data on productivity, cropping pattern, as well as land preparation, seeding, and fertilizer application techniques. Figure 10. shown field appearance of rice, maize, and cassava.

Figure 10. Field Appearance of Rice, Maize, and Cassava

3.3 Post-field Analysis
Post-field analysis is the last step in estimating the crop production in the study area. The analysis included crop production and productivity data management, map of crop production estimates, and cropping calendar. A set of data obtained from direct measurements and interviews shows that the highest crop productivity is found in irrigated agricultural land (Rice-N) (Cassava-S2) (Maize-N) and rainfed agricultural land (Rice-N) (Cassava-S2) (Maize-S2) for rice and cassava. Meanwhile, maize is mostly found in irrigated agricultural land (Rice-S1) (Cassava-S2) (Maize-N), irrigated land (Rice-S1) (Cassava-S2) (Maize-S1), and dry agricultural land (Rice-S2) (Cassava-N) (Maize-N).

3.4 Data on Crop Production
The assessment of crop production has been conducted with various methods including land suitability approach, commonly referred to as crop production estimation. This study estimated the productions of rice, maize, and cassava and resulted in 18 land suitability classes with different production and productivity. Irrigated agricultural land, rainfed agricultural land, and dry agricultural land have respectively seven, four, and seven land suitability classes. Here are three examples of land suitability and corresponding crop production found in the study area: 1) the land suitability of irrigated agricultural land for (Rice-N) (Cassava-S2) (Maize-N) produces 24,381.267 kg/are of rice and 48,762.533 kg/are of cassava; 2) despite the land suitability of rainfed agricultural land for (Rice-N) (Cassava-S2) (Maize-N), field survey showed that this specific land was used for rice production, i.e. 266,867,520 kg/are; and 3) dryland with land suitability for (Rice-N) (Cassava-S2) (Maize-N) produces 573,876 kg/are of maize and 143,469 kg/are of cassava. The agricultural productivity in the study area are presented in detail in Table 1.
Table 1. Table of Production per Land Suitability (Source: Field Survey and Data Processing, 2014)

| Land Suitability                        | Productivity | Total Production |
|-----------------------------------------|--------------|------------------|
|                                         | R  | M  | C  | R  | M  | C  |
| Irrigated Agricultural Land - (Rice-N)(Cassava-S2)(Maize-N) | 2,000 | 0   | 2,000 | 24,381 | 0.000 | 48,762 |
| Irrigated Agricultural Land - (Rice-S1)(Cassava-S2)(Maize-N) | 950  | 500 | 0   | 4,803  | 3,792.044 | 0.000 |
| Irrigated Agricultural Land - (Rice-S1)(Cassava-S2)(Maize-S1) | 950  | 500 | 0   | 277,080 | 218,748.088 | 0.000 |
| Irrigated Agricultural Land - (Rice-S1)(Cassava-S2)(Maize-S2) | 1,472 | 0   | 0   | 48,210,592 | 0.000 | 0.000 |
| Irrigated Agricultural Land - (Rice-S2)(Cassava-S2)(Maize-N) | 0   | 0   | 40  | 527,170 | 0.000 | 6,589 |
| Irrigated Agricultural Land - (Rice-S2)(Cassava-S2)(Maize-S1) | 200  | 200 | 0   | 63,947  | 31,973.833 | 0.000 |
| Irrigated Agricultural Land - (Rice-S2)(Cassava-S2)(Maize-S2) | 1,266 | 0   | 0   | 289,847,814 | 0.000 | 0.000 |
| Rained Agricultural Land - (Rice-N)(Cassava-S2)(Maize-N) | 1,600 | 0   | 0   | 266,867,520 | 0.000 | 0.000 |
| Rained Agricultural Land - (Rice-S1)(Cassava-S2)(Maize-S1) | 0   | 0   | 20  | 0.000  | 0.000 | 76,042 |
| Rained Agricultural Land - (Rice-S2)(Cassava-S2)(Maize-S2) | 0   | 40  | 40  | 2,941.040 | 1,470 | 0.000 |
| Rained Agricultural Land - (Rice-S2)(Cassava-S2)(Maize-S2) | 0   | 0   | 20  | 0.000  | 0.000 | 97,939 |
| Rained Agricultural Land - (Rice-N)(Cassava-S2)(Maize-N) | 0   | 40  | 20  | 0.000  | 573,876 | 143,469 |
| Dry Land - (Rice-S1)(Cassava-S2)(Maize-N) | 0   | 87  | 0   | 0.000  | 18,786 | 0.000 |
| Dry Land - (Rice-S1)(Cassava-S2)(Maize-S1) | 0   | 87  | 0   | 0.000  | 267,903 | 0.000 |
| Dry Land - (Rice-S1)(Cassava-S2)(Maize-S2) | 0   | 40  | 40  | 0.000  | 122,379 | 61,189 |
| Dry Land - (Rice-S2)(Cassava-S2)(Maize-N) | 180  | 500 | 180  | 9,758.082 | 40,658 | 4,879 |
| Dry Land - (Rice-S2)(Cassava-S2)(Maize-S1) | 0   | 40  | 40  | 0.000  | 206,128 | 103,064 |
| Dry Land - (Rice-S2)(Cassava-S2)(Maize-S2) | 0   | 18  | 18  | 0.000  | 375,610 | 372,095 |
| **Total**                                  | **605,833,068** | **1,862,796** | **915,502** |

Rice is a commodity with the highest production because Karangasem Regency relies on subak irrigation system for its production. This system divides water that flows from the upstream into rice fields periodically in order to provide a good rice growth and sustainable rice yield rate. Maize production results in a higher yield than cassava production because the former is perceived as a commodity with higher selling price; therefore, maize is widely grown and highly produced. Every land suitability results in different production due to differences in land characteristics. Consequently, the land capability for crop growth and the crop production also vary. Information on crop production is essential not only for understanding land suitability but also for estimating the crop production in every district. The results of crop production in every district of Karangasem Regency were obtained from the calculation of productivity, harvest age, and agricultural land size. The annual production was assessed using the multiplication of average productivity by harvest age. From the annual production, the total production was also known and, then, used for estimating the production in the whole regency, which was divided again into crop production in every district. The highest rice production is found in Karangasem District, i.e. 128,728.428 kg, while the lowest production is found in Kubu District, i.e. 25,482.400 kg. Maize is highly produced in Abang District, i.e. 420,600.491 kg,
and least produced in Sidemen District, i.e. 65,912,957 kg. Meanwhile, cassava is mostly produced in Kubu District, i.e. 355,946,087 kg, and least produced in Manggis District, i.e. 13,807,417 kg. The crop production in every district is presented in detail in Table 2.

### Table 2. Production per Commodity per District in Karangasem Regency
(Source: Data Processing, 2014)

| District   | Rice      | Maize     | Cassava   |
|------------|-----------|-----------|-----------|
| Abang      | 69,665.613| 420,600.491| 204,638.574|
| Bebandem   | 80,353.590| 221,084.407| 79,217.263|
| Kubu       | 25,482.400| 324,557.023| 355,946.087|
| Manggis    | 67,293.266| 127,711.610| 13,807.417|
| Karangasem | 128,728.428| 364,512.098| 113,078.060|
| Rendang    | 31,324.283| 214,561.226| 75,929.621|
| Selat      | 64,129.358| 104,917.390| 39,234.722|
| Sidemen    | 73,196.902| 65,912.957| 21,564.773|
| Total      | 540,173.840| 1,843,857.202| 903,416.517|

3.5 Map of Agricultural Production Estimates

Karangasem is one of the regencies in Bali that has a great agricultural potential. According to [2] this regency produces 77,870.18 tons of rice, 22,838.94 tons of maize, and 107,903.97 tons of cassava from the widely found agricultural land in 8 districts in Karangasem Regency. This statistics is slightly different from the crop production estimates in 2014, which were calculated based on land suitability evaluations and interviews. However, the classification of land suitability required further field check because the results of image interpretation were different from the actual condition. Such difference occurred due to the influence of several factors like the subak irrigation system. Every commodity has different criteria for land characteristic and suitability.

Every district has various classes of land suitability for rice production. Figure 11 shows that the highest rice production is in Karangasem District with a total yield of 128,728.428 kg, the second highest productions is in Bebandem and Sidemen with total yields of 80,353.590 kg and 73,196.902 kg, respectively. The land in these three districts is mostly used for irrigated agricultural land, rainfed agricultural land, and dry agricultural land with ‘high suitability’ (S1) for rice. Despite the vast dry and rainfed agricultural lands in Bebandem District, the district is still able to produce a significant amount of rice due to the presence of subak irrigation system. This system ensures reliable water supply in dry seasons. Kubu and Rendang Districts are mostly non-agricultural land and drylands with very low productivity, i.e. 25,482.400 kg and 31,324.283 kg, respectively. Even though Rendang District has some irrigated agricultural lands, its productive lands have limited suitability for rice production. Mountainous area and dry climate are the factors that significantly influence the rice production in this district. The government is developing various programs that aim to improve national food security, particularly for national-level subsistence farming. One of the programs is enhancing the quality of intensification, optimization, and extensification of agricultural land in order to ensure the annual availability of rice [8].

Maize is the second greatest commodity after rice, which is usually grown in the transition period between two rice cultivation seasons. This cropping rotation aims to maintain the soil quality and break the chain of pests like rats and leafhoppers. Figure 12 shows the maize production estimates in Karangasem Regency. High maize production often associates with the capability of maize to grow in either dry or wet land. The highest maize production is found in Abang District with a total yield of 420,600.491 kg. This district mostly produces rice; but maize is also suitable for the mountainous topography, dry climate, and limited access to water supply in the district. The second highest maize yield is found in Kubu and Karangasem Districts that produce 324,557.023 kg and 364,512.098 kg,
respectively. Kubu District has the most suitable land (S1) for maize. Bebandem and Rendang Districts produce the third highest maize yield, i.e. 221,084.407 kg and 214,561.610 kg, respectively. Meanwhile, Selat and Manggis Districts have lower maize yields, i.e. 104,917.390 kg and 127,711.610 kg, respectively. In Selat District, maize is produced in lands that are suitable for irrigated agriculture (Rice-S1) (Cassava-S2) (Maize-S1) and three types of dryland farming, namely (Rice-N) (Cassava-S2) (Maize-S2), (Rice-S1) (Cassava-S2) (Maize-S1), and (Rice-S2) (Cassava-S2) (Maize-S2). Meanwhile, in Manggis District, maize is grown mostly in lands that are suitable for irrigated agriculture (Rice-S1) (Cassava-S2) (Maize-S1). Sidemen District has the lowest maize production in the regency, i.e. 65,912.957 kg. In this district, maize is grown in lands that are suitable for irrigated agriculture (Rice-S1) (Cassava-S2) (Maize-S1) and dryland farming (Rice-N) (Cassava-S2) (Maize-N). Maize is also cultivated in hilly to mountainous areas where the few productive lands are beyond the reach of subak irrigation system.

**Figure 11.** Rice Production Estimated Map (Source: Data Processing, 2014)

**Figure 12.** Maize Production Estimated Map (Source: Data Processing, 2014)

**Figure 13.** Cassava Production Estimated Map (Source: Data Processing, 2014)

**Figure 14.** Comparison Map of Crop Production Estimates (Source: Data Processing, 2014)
Cassava is an alternative crop during the transition period between the cultivations of other crops. It is usually grown in dryland, barren land, and water-deficit area. Figure 13. shows that Kubu District produces the highest cassava yield, i.e. 355,946.087 kg. Abang District also has a high cassava production, i.e. 204,638.574 kg. Meanwhile, Rendang, Bebandem, and Karangasem Districts have lower cassava yields, ranging from 39,100 kg to 113,000 kg. The cassava productions in Karangasem, Bebandem, and Rendang District yield 113,078.060 kg, 79,217.263 kg, and 75,929.621 kg, respectively. The lowest cassava productions are found in Selat District, which vary between 21,000 ton/year and 39,000 ton/year, and Sidemen and Manggis Districts, which vary between 14,000 ton/year and 21,000 ton/year. Cassava is categorized as the highly suitable crop for every rainfed agricultural land, irrigated agricultural land, and dryland in every district because it can grow almost everywhere in the regency, i.e. in areas with no or little water and flat to mountainous topography.

The comparison between these three crop production estimates in Karangasem Regency is presented in a map, as shown in Figure14. The map shows that Kubu District has the highest cassava yield, as compared to its maize and rice productions. The land characteristics of this district are suitable for cassava productions. Meanwhile, the proportion of maize production in every district is mostly higher than the proportions of the other two commodities. Therefore, maize production is highly suitable and productive in Karangasem Regency, Bali. The highest maize yield is found in Abang District and, followed by, Karangasem District. Maize stays productive throughout the year in spite of its various cropping patterns. The opposite is true for rice production, which has the lowest yield among the commodities. The subak irrigation system has an open-and-close mechanism that becomes both opportunity and challenge for rice growth due to the strong dependence of rice on water availability. This irrigation system significantly promotes the rice production in agricultural lands located close to the water resource or, in other words, with high probability to obtain water. On the contrary, this system becomes the primary obstacle of rice productions in agricultural lands that rarely receive irrigation water. Consequently, instead of planting rice, farmers tend to cultivate crops with water-deficit tolerance like maize and peanuts in order to sustain land productivity.

3.6 Map of Cropping Calendar
Cropping calendar is a schedule for the potential cropping and harvesting time of food crops. This study provided cropping calendars for rice, maize, and cassava in Karangasem Regency, Bali, as shown in Figure 15. Creating the map of cropping calendar aimed to understand the cropping schedule in one year based on the land suitability of the study area. Cropping pattern and rotation is spatially determined by land suitability and water availability or subak irrigation system. Bali is historically known to have unique cultural tradition and religious commitment, one of which is in the form of community organization named subak. Subak is a group of indigenous farming communities that is based on Balinese tradition and culture, i.e. the Hindu philosophy “Tri Hit Karana”. It functions as a social organization in the field of local water resource management for agricultural lands. Subak is an irrigation sub-system whose main function is to regulate irrigation water utilization so that farmers can irrigate their fields sufficiently, fairly, and equally. So far, Subak has provided a very effective and strategic role in water resource management, particularly for irrigation, by ensuring water availability and utilization in Bali.
The cropping patterns may be diverse even within the same land suitability because of the influence of subak irrigation system. The crops grown in an area are possibly different from which crops the area is suitable for. As an example, the suitable land for the irrigated farming of (Rice-N) (Cassava-S2) (Maize-N) in the study area is actually cultivated for rice and cassava. In this agricultural land, rice is grown once a year in December and harvested in March, while cassava is grown twice a year in February-July and August-January. In addition, the suitable land for the rainfed (Rice-N) (Cassava-S2) (Maize-N) farming is actually cultivated for rice and cassava, even though (Rice-N) means that this specific land is not suitable for rice production. The difference between the results of land suitability and actual cropping pattern in the study area is likely caused by subak irrigation system. Both cropping pattern and calendar are influenced not only by the characteristics of land suitability but also by other factors like subak irrigation system, weather, and economic condition. As a farming community, not only does subak maintain the regulation of irrigation water, but it also provides information on crop seed, cropping schedule, harvest time, and even agricultural land management. The irrigation water regulation in subak is different according to dry and wet months. In wet months, subak does not give any significant influence on farming practices; therefore, farmers can conveniently grow any crops. However, in dry months, farmers have to comply with the open-and-close system of subak. In other words, subak irrigation system affects the cropping patterns in dry months.

4. Conclusion
According to the study results and the previously formulated objectives, remote sensing and Geography Information System are essential to estimate the crop production and productivity of, for
instance, rice, maize, and cassava in Karangasem Regency, Bali using land suitability approach and matching technique. The total crop production estimates in Karangasem Regency are 540,173.84 kg/year of rice, 1,843,857.20 kg/year of maize, and 903,416.52 kg/year of cassava. The cropping pattern and schedule in every land suitability class are different due to the influence of subak irrigation system, weather, and the economic condition of farmers in Karangasem Regency.

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