Original Paper

Determining Potential Wheat Growing Areas in Indonesia by Using the Spatial Compromise Programming Technique

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Abstract

In this study, we sought to identify potential wheat growing areas by considering five factors. The factors were wheat productivity, harvest timing, labor sufficiency ratio, economic relative value and potential profit. Productivity and harvest timing were derived from a wheat simulation model, while the other three factors were calculated from data consisting of labor availability, the prices of agricultural commodities, and agricultural production costs. The labor sufficiency ratio was defined as the ratio between the number of required laborers and number of available laborers during the wheat growing period. The relative economic value was calculated as the ratio of the potential profit gained from wheat growing to the profit gained from a major existing crop, while potential profit was calculated as the difference between potential revenue and production cost. To allow for spatial variability in these criteria, we applied spatial compromise programming (SCP), an enhanced method of compromise programming (CP) by integrating a conventional CP with geographical information system (GIS) tools.

The best compromise solution is indicated by a minimum Lp metric value, the cumulative distance of all criteria from ideal values. The value of this metric depends on the weighting applied by decision makers to each criterion. Lombok Island was chosen as the study area. By using default weighting values, it was found that potential wheat growing areas were located in the middle of the island.

Keywords

wheat, potential growing areas, spatial compromise programming

Introduction

Indonesia consumes a significant amount of wheat annually. The statistical data showed there is an increasing of annual wheat consumption level from 6.18 kg per capita in 1984, increased to 9.17 kg per capita in 1991, and reached 17.91 kg per capita in 2004. Even this value was still far below the wheat consumption

level of other countries, such as Japan which consumes more than 45 kg per capita per year, Indonesia has ranked the fourth of the largest wheat importer countries in the world which is about 4.1 mt per year to cover all of the demand (Pasandaran, 1995; natiomaster.com, 2004).

As long as there is the enough supply available in the market supported by enough purchasing ability, importing wheat does not seem to be a problem. But if

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the condition is like what Indonesia experienced around year 1998 when multidimensional crisis hit and depreciated rupiah (Indonesia's currency), being totally dependent on importing wheat is very susceptible and risky.

An alternative way to release Indonesia from the import dependency, however this is not an easy task since wheat is a temperate zone origin crop, is by producing the local wheat. The data from experimental sites in Indonesia showed that wheat could yield about 1.37 tons/ha until 3.2 tons/ha (Salim & Zaini, 1992). Furthermore, Gusmayanti (2000) has tried to simulate the potential wheat yield based on agro-climate throughout the country and found that some highland areas in the eastern part of Indonesia may be a potential area for wheat growing.

In the other hand of promising findings mentioned above, there are many involving factors that should be evaluated before deciding to initiate wheat cultivation in Indonesia. The factors may consist of agro-climatic suitability, environmental as well as socio-economic impacts. Considering all these factors will give comprehensive understanding of the crop. However, in this study we limit the analysis to only several factors considered as decision criteria for determining wheat potential growing areas by using spatial compromise programming.

Methods and Material

Compromise Programming

The *compromise programming* (CP) is one of multiple criteria decision making methods. The underlying concept of CP is that many optimization problems involve multiple objectives which some of them are conflicting to each other and need to be considered simultaneously. It may not possible to find solution that optimal with respect to all objectives. Instead, CP offers the solution that close enough to the ideal point (Zeleny's axiom).

The closeness of the criteria from the best solution is measured by using a distance metric. This distance is measured for each criterion and summed up together into Lp value. To accommodate the problem

causing by a different units of criteria, the relative distance is introduced and the whole formula for calculating Lp metric value become as equation shown below:

$$L_p(i) = \left[\sum_{j=1}^n w_j^p \cdot d_j^p \right]^{1/p} \quad (1)$$

where j is criterion (criterion 1, criterion 2,..., criterion n), p is a parameter and d is the relative distance of each criterion value from its ideal point, as formulated in equation 2.

$$d_j = \frac{|z_j^* - z_j(i)|}{|z_j^* - z_j^*|} \quad (2)$$

where z_j^* and z_j are the ideal (best) and anti ideal (worst) points, while $z_j(i)$ is the value of criterion j for solution i . The best compromise solution is indicated by minimum Lp metric value.

The decision maker interferences in decision making process are applied when determining the weight (w_j) of each criterion and value of parameter p . Weight is a measure of relative utilities (priority) of decision makers on a certain criterion compared to other criterion, while p is a measure of their concern on deviation of criterion value from its ideal point. The weight value is ranged between 0 and 1, with the total value of all criteria is equal to 1. Practically, Lp metric is calculated at three values of L_1 , L_2 , and L_∞ which are called *Manhattan Metric*, *Euclidian Metric*, and *Tchebycheff Metric* respectively (Chen *et al.*, 1999).

Criteria Selection

We selected five criteria which consist of agro-climate and agribusiness aspects of wheat growing. The agro-climate criteria were wheat productivity and harvest timing (days after sowing), while agribusiness criteria were labor sufficiency ratio, economic relative value and potential profit. Each of criteria is described in the following paragraphs.

Wheat Productivity. The value of this criterion was derived from a wheat simulation model which is called Shierary wheat model (Handoko, 1992). The crop model can simulate daily gains and loses of crop biomass, water balance and nitrogen balance. By inputting daily agro-climatic data and several cultivation scenarios consist of nitrogen fertilizer dosage and watering, we run the model and mapped the result to get the spatial variation of yield. The preferable values of this criterion were equal or more than 2.5 ton/ha.

Harvest Timing. The period calculated from sowing till harvest time has correlation with altitude. Since temperature decreases as altitude increases, the duration for collecting thermal unit is longer in highland than that is in lowland areas. It gives crops a longer period to accumulate dry matter in the highland areas. In the other side, longer harvest time can decrease sowing frequency per year.

Labor Sufficiency Ratio. The labor availability is calculated by comparing the number of available laborers in a certain area to the number of required laborers during wheat growing season which is assumed to be ten laborers per hectare and scaled to 1. It is the maximum value meant that the excess laborers did not be counted.

Economic Relative Value. The economic relative value is an indicator of the chances to replace the established crops with wheat. The value was defined as a ratio between the potential profit gained from wheat growing and the profit gained from a major existing crop. If the value is greater than 1, it means that wheat is economically more profitable than the existing crops.

Potential Profit. The potential profit is calculated to get the actual income gained from wheat growing. It was defined as the difference between potential income (potential yield multiplied by selling price) and production cost, which assumed only bear from seed, laborers, and nitrogen fertilizer.

As we considered spatial unit (i.e. village or pixel) to be the solutions which would be analyzed their Lp metric value in decision making process, we used Geographical Information System (GIS) tool to assist the calculation and the spatial analysis.

Dataset

Materials used in this study were statistical data and maps. The data included climatic, soils, wheat crop, labor availability, the prices of agricultural commodities, and agricultural production costs. The information of the major existing crop in the location was needed as well to find the relative economic value in comparison to wheat crop. Whereas maps consisted of administrative map, topographic map and land-use map.

Procedure

All criteria were prepared in form of maps (layers). The first two criteria were derived from a crop simulation model, whereas the others were derived from agricultural economic data. These maps (layers) would be overlaid on top each other. By applying weight associated with the layers, it resulted a single map of Lp metric value. These steps (as shown in Fig. 1) were assisted by GIS tools.

The weight might be determined directly by applying value between 0-1. It also can be made by applying preference comparison of each criterion, continued by calculating the priority (pear-wise comparison method).

Regarding to simplicity in simulation we determined default weight values which assumed that the decision maker has high priority on yield production. This assumption was based on the purpose of seeking for the possibility to release the country from wheat import dependency. Therefore, the high potential yield areas would be appreciated more by the decision maker compared to other criteria. The default values were 0.4, 0.2, 0.2, 0.1, and 0.1 respectively for wheat productivity, harvest timing, labor sufficiency ratio, economic relative value and potential profit.

Result of Case Study In Lombok Island

In the consideration of data availability, we chose Lombok Island as a study case area. This choice was also supported by the previous study stating that

the eastern areas of Indonesia have the better agro-climatic suitability for wheat than those in the western (Gusmayanti, 2000).

The criteria of yield and harvest were simulated together by using the crop simulation model. There were six scenarios applied during the simulation which were the combination of the nitrogen fertilizer dosage (0, 100, and 200 kg N/ha) and the watering (rainfed or irrigated). Result of the simulation showed that water shortage is the limitation factor rather than soil nitrogen status in producing wheat in Lombok Island. Applying irrigation water during water shortage period may gain a higher potential yield.

Fig. 1. Scheme of Lp metric value calculation

On the average, the potential yield in Lombok Island is about 1.5–3 ton/ha. The better result (> 3 ton/ha) might be obtained in the northern part of the island (highland areas). It is due to the cooler weather in the highland areas so that crop accumulates more dry matter, but at the same time crop needs a longer period to achieve a certain growth stage. It leads to a limited growing frequency per year.

The harvest time in Lombok Island is about 3 months until more than 6 months. As explained above, the late harvests are found in the highland areas where temperature is relatively cooler than that is in lowland areas.

The number of laborers working in agricultural sector was about half of total available laborers. Based on calculation result, it was shown that labor sufficiency

ratio is relatively higher in the middle areas of the island, i.e. 0.3–0.6.

The relative economic value was calculated by comparing the potential profit of wheat to the potential profit of rice (as a major existing crop in Lombok Island). Most part of the island has relative economic value less than one, which meant that rice was more profitable than wheat crop was. However, wheat crop is still feasible to grow in the island, since it is more tolerant to dry season than rice is. The distribution of potential profit on the cultivation scenarios tended to follow distribution pattern of wheat productivity. It regards to the application of 40% of weight value into the wheat productivity criterion.

The simulation result of one scenario is shown in Fig. 2 (100 kg N/ha with irrigation). The most preferable values were colored in dark green while the light red indicated the most un-preferable values of each criterion. It shows that the preferable values of the criteria were not always found at the same region, and some of them were contradictory to each other. This is the typical condition where CP may very useful to solve the problem.

The Lp metric was calculated at three different values of p (i.e. $p=1$, $p=2$, $p=\infty$). The p value indicates preferences of decision maker in considering deviation of each criterion value from its ideal value. The $p=1$ means that the decision maker does not consider the maximum deviation, $p=2$ means that he considers the maximum deviation value proportionally, while $p=\infty$ means that he extremely cares about the data deviation. The result showed that $L_{p=1}$ values were the maximum, followed by $L_{p=2}$ and $L_{p=\infty}$ respectively. Even using different values of p , decision result of best compromise solutions were found around the same areas, which were located in the middle part of Lombok Island. Fig. 3 presents the maps of Lp metric value at one of cultivation scenarios, in this case we selected scenario of 100 kg N/ha with irrigation to be displayed.

Conclusion

The determination of wheat potential areas can be done by applying compromise programming technique which was modified into spatial based technique. The justification of suitable areas for wheat growing is using five criteria i.e. potential yield, harvest time, labor sufficiency ratio, economic relative value, and potential profit. The recommendation may vary depend on weight

of each criterion applied by decision makers indicating their priority or interest.

Case study in Lombok Island showed that wheat potential yield was about 1.5 -3.0 ton/ha, while harvest time was in range of 80 -100 days after sowing. The better yield was found in highland areas (northern part of the island). The laborer was relatively sufficient in the middle part of the island. The economic value of wheat was less than rice in the most part of the island,

Fig. 2. Maps of criteria values at one of scenarios (100 kg N/ha with irrigation)

while potential profit was vary depend on cultivation scenarios. By applying weight of 0.4, 0.2, 0.2, 0.1, and 0.1 for potential yield, harvest time, labor sufficiency ratio, economic relative value, and potential profit respectively, it was found that potential areas were located in the middle areas of the island

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Fig. 3. Maps of Lp metric values at one of cultivation scenarios (100 kg N/ha with irrigation)

空間調和化手法によるインドネシアの 小麦栽培可能性地域の決定

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要旨

本研究は5つの要因を考慮して小麦栽培の可能性を検討した。要因として小麦生産力、収穫期間、労働生産性、相対的経済関連要因、潜在的利益などがある。後の3要因は労働力利用可能性、農産物価格および生産費などから求め、小麦生産力及び収穫期間は作物シミュレーション・モデルから求めた。

労働生産性は小麦の栽培期間中の労働必要量と利用可能労働量の比率で定義した。相対的な経済価値は小麦栽培による潜在的な利益と生産費の差から求めた潜在利益と主な既存作物から得られる利益との比率と仮定した。これら基準と空間変動に対応するため、本研究ではGISツールに従来の調和化プログラミング(CP)を拡張強化した空間調和化プログラミング(SPC)手法を適用した。最適な調和化では理想値からすべての基準に最小Lpメトリック値でその累積距離が示される。それらは意思決定者によるウエイト値の決定により変わるが、研究対象のロンボク島では初期ウエイト価値の適用により、小麦の栽培適地が島の中央部に位置している結果が得られた。

キーワード

小麦、可能性成長地域、空間の調和化プログラミング

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