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GIS 기반의 토양 및 기후조건 통합 배 과수의 적지 평가

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GIS-based Land Suitability Assessment for Pears (*Pyrus*) Using Soil and Climate Conditions in South Korea

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ABSTRACT

Land suitability assessments for agricultural crop production determine the suitability of an area in terms of crop yields. We employed the maximum limiting characteristic method (MLCM) and an analytic hierarchy process (AHP) to assess land suitability for Pears (*Pyrus*) in all Korean provinces (Dos). In general, suitability grades according to the MLCM were much lower than those according to the AHP. The MLCM determined that suitable areas (S1, S2, and S3) exist on 19.55% of the land, whereas 99.08% of the land was classified as suitable by the AHP. Based on information on pear farms in each Korean province in 5 years (1982, 1987, 1992, 1997, 2002, and 2007), the proportion of suitable land area according to the MLCM in each province as compared to all suitable areas was closer to the proportion of areas covered by pear farms in the 5 years in each province and also to the proportion of pear farm areas in 2007 in each province. Based on the assumption that if a province has more suitable areas for pears, more pears will be cultivated in that province, the results of the MLCM can be regarded as more accurate than those of the AHP.

***Key words*: Land suitability assessment, Pear, Maximum limiting characteristic method, AHP**

I. INTRODUCTION

Land suitability assessment is a crucial issue that affects land use and environmental planning; it defines the suitability class of an area for a specific use, such as crop production (Anderson, 1987; Xiang and Whitley, 1994). In the geographical information system (GIS) environment, land suitability evaluation can be assessed by techniques that are based on multiple-criteria decision-making (Pereira and Duckstein, 1993). Basically, land suitability assessment can be regarded as a multi-criteria problem, and the major issue for suitability analysis is to analyze the individual or additive effects of multiple factors (Mendoza, 2000). Also, developments in geoinformatic techniques, such as remote sensing, GIS, and GPS, allow us to prospectively analyze land suitability assessments to increase crop production and conserve

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agricultural lands (Brinkman and Young, 1976).

When attempting to combine multiple factors, it is possible to use the most-limiting characteristic method (MLCM) for land suitability assessment (Rilwani, 2011). The MLCM is a classical methodology that assigns the most-limiting (worst- graded) factor as the representative value for an entire site. Elsheikh *et al.* (2013) employed the MLCM for soil variables in their decision and planning support tool for tropical and subtropical crops. Kim *et al.* (2016) conducted land suitability assessment for apples and pears with soil and climate information using the MLCM, and suggested that altenative ways should be carefully considered for increasing the accuracy since the method can be influenced by one downgraded factor.

The analytic hierarchy process (AHP) is a useful alternative when enough data is not available, in that the AHP relies less on real field data and more on the opinions and observations of experts. Waqar *et al.* (2013) adapted an AHP method to compute significance weights for parameters involved in cultivating rice.

In this research, we employed two methods, MLCM and AHP, to provide land suitability assessments for pear (Pyrus) trees in South Korea and compared the results of the two assessments. We typically analyzed the percentage of each grade in each province, or "Do," and compared differences between the percentage of suitable areas in each province according to each method and the proportion of real pear farms in each province. We compared the two methods based on the actual location of pear fields in southwestern South Korea by assessing the average suitability score. In doing so, we tried to shine light on each method's results and, therefore, tried to provide valuable outcomes of land suitability assessments for pear production to anyone who wishes to grow pears.

II. MATERIALS AND METHODS

2.1. Study areas

We conducted land suitability assessments for pears in South Korea. South Korea is located on the southern part of the Korean Peninsula between latitudes 33° and 39° N and longitudes 124° and 130° E (KOSIS, 2018). South Korea can be broadly divided into four areas: high mountains and narrow coastal plains in the east; broad coastal plains, river basins, and rolling hills in the west; mountains and valleys in the southwest; and, mainly, the broad basin of the Nakdong River in the southeast (SKG, 2012).

Table 1. Classification system for soil and climate for pears

Variable	S1	S2	S3	N1
Pebble content	<10	10-35	10-35	>35
Slope (%)	0-7	7-15	15-30	>30
Soil texture	Clay loam, Silt clay loam	Sandy loam, Silt sandy loam	Clay	Sand, Gravelly soil, Gravelly sand
Drainage classes	Well	Well but too excessive	Moderately well	Poor
Available soil depth	>100	50-100	20-50	<20
Temperature during growing season (℃)	$15 \leq x < 18$	$14.4 \leq x < 15$, $18 \leq x < 18.7$	$13.5 \leq x < 14.4$, $18.7 \leq x < 19.5$	$X < 13.5$, $X \leq 19.5$
Mean annual temperature (℃)	$8 \leq x < 11$	$7.2 \leq x < 8$, $11 \leq x < 12.5$	$6.5 \leq x < 7.2$, $12.5 \leq x < 14$	$X < 6.5$, $X \geq 14$

* S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, N1: Currently not suitable, N2: Permanently not suitable (The areas with gully erosion, forests or uncultivated grassland, cemeteries, urban settling, wasteland, artificial soil and water were classified as N2 areas.).

South Korea experiences heavy precipitation in the summer during a short rainy season that is also hot and humid – the temperature in the summer can be over 30°C in all regions of the country. South Korea also has very cold weather in the winter; the minimum temperature can be below -20°C. South Korea has four clear seasons, which are spring, summer, autumn, and winter (USLC, 1990).

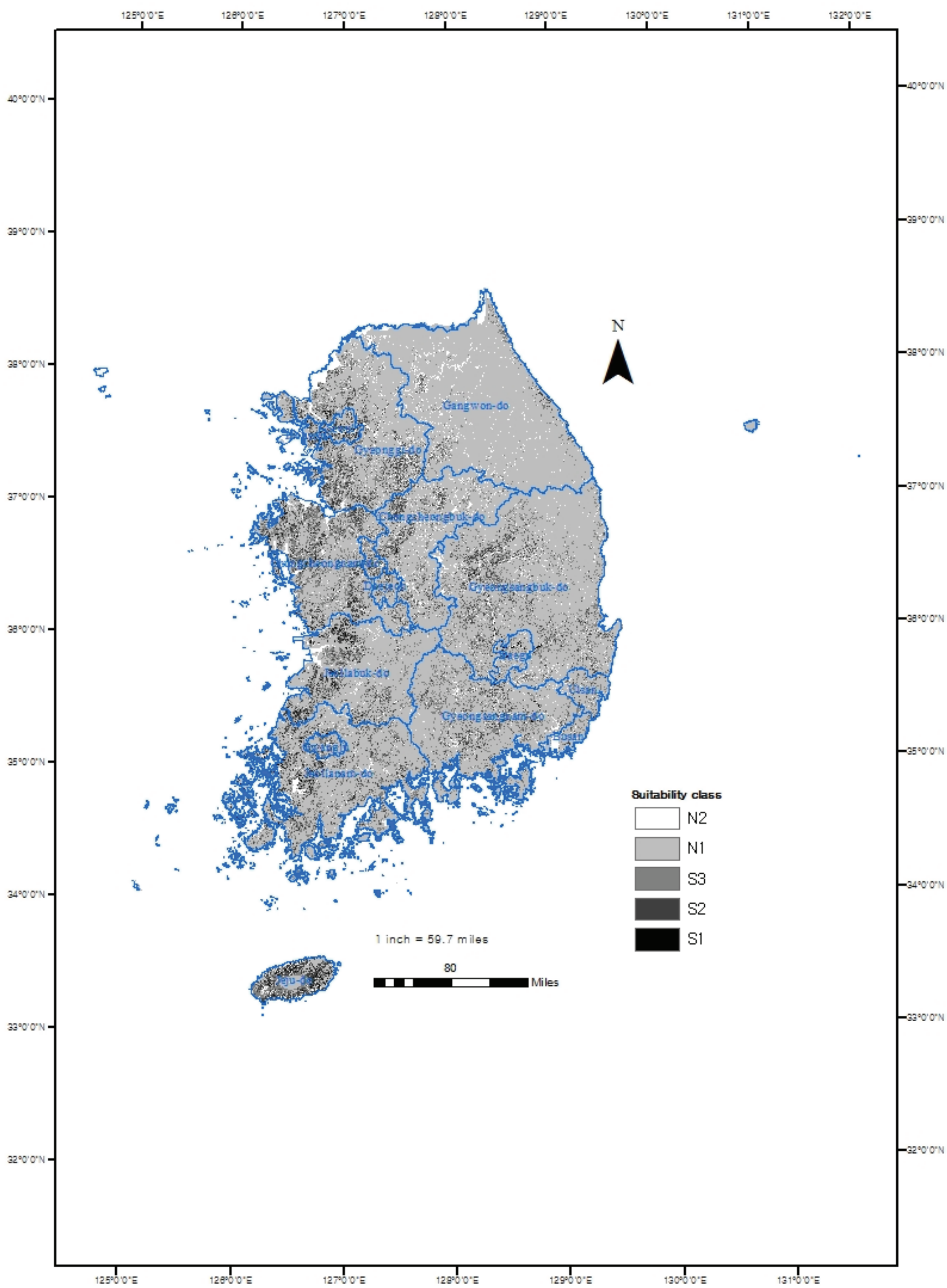

Fig. 1. Map of land suitability classification for pear trees generated using the MLCM.

2.2. Data and methodology

The pear is in the family Rosaceae and belongs to the genus Pyrus (Potter *et al.*, 2007). A pear tree's flowers have five petals and are usually white, but can, rarely, be tinted yellow or pink, and are 2–4 centimeters in diameter (GSN, 2010). Pear Bureau Northwest reported that about 3,000 known varieties of pears are grown worldwide and *Pyrus pyrifolia* is known as the main breed in South Korea. The cultivation area of pears was 10,861ha in 2017 (PBN, 2015; KOSIS, 2018).

The Food and Agriculture Organization (FAO) provides the guidelines for land suitability classification as a framework (FAO, 1976). The FAO classifies land broadly into two orders, S (suitable) and N (not suitable). In detail, the FAO sub-classifies suitable land into three rankings, S1 (highly suitable), S2 (moderately suitable), and S3 (marginally suitable). The FAO sub-classifies the N order into two classes, N1 (currently not suitable) and N2 (permanently not suitable). We use a score representing the relative intensity of suitability of an area: 0, 5, 10, 15, and 20 for N2, N1, S3, S2, and S1 land, respectively. As the climate database, information from 1981 to 2010 was used based on 30-meter grid cells (NIHHS, 2010). We also used soil information as a vector-based database with a map scale of 1:25,000 (NAS, 2016), which is later transferred into raster map that can be matched with climate maps. Land was originally assigned values for soil information in terms of yield. The classification system for soil and climate is presented in Table 1.

We used two methods, the MLCM and the AHP, in this research. The MLCM assigns the most limiting value of all factors examined to the site as a whole. The AHP is a structural technique that can be used to analyze complex decisions. It was invented by Thomas L. Saaty in the 1970s and, since then, it has been studied and adjusted in diverse areas related to decision making (Saaty, 2012; Saaty and Peniwati, 2007; Saracoglu, 2013). We asked experts in pears and the interaction of pear trees with soil and climate for an AHP analysis. The AHP scale for pairwise comparisons is presented in Table 2.

As reference data to check the results of the two methods, we used a geographic database regarding land covered by pears farms in South Korea, which is presented in Table 3 (KOSIS, 2018). It provides the areas of pear cultivation in each province, or "Do" in the years 1982, 1987, 1992, 1997, 2002, and 2007.

Table 2. The AHP scale for pairwise comparisons

Intensity of importance	Definition
1/3	Strong unimportance
1/2	Moderate unimportance
1	Equal importance
2	Moderate importance
3	Strong importance

Table 3. Pear farm areas (Unit: ha).

Provinces	1982	1987	1992	1997	2002	2007
Gyeongsangbuk-do	448.4	388.4	853.6	2,686.6	3,669.3	2,818.6
Jeju-do	1.4	0	0	3.2	40.5	5.7
Gyeongsangnam-do	1,074.0	867.2	801.6	1,294.0	1,792.4	1,481.4
Jeollanam-do	1,140.6	1,237.9	1,816.5	4,651.1	5,163.1	4,804.1
Jeollabuk-do	274.0	201.8	380.7	1,420.0	1,713.6	1,248.0
Chungcheongnam-do	1,450.6	1,222.6	1,620.5	4057.9	5,175.2	4,126.9
Chungcheongbuk-do	274.0	201.8	380.7	1,420.0	1,713.6	1,248.0
Gangwon-do	342.3	245.6	270	418.2	555.9	383.6
Gyeonggi-do	3,448.1	2,283.0	2,600.1	4,114.5	4,908.4	4,259.7

III. RESULTS

3.1. Pear classification by MLCM

The result of the MLCM analysis is presented in Table 4. The results show that 5.51% of the land was classified as N2 and 74.94% of the land was classified as N1, which is a total of 80.45% of the land classified as unsuitable for pear cultivation. The rest of the land was classified as S3, S2, and S1: 13.30%, 5.77%, and 0.48% respectively, for 19.55% of the land in total. Therefore, according to the MLCM, suitable areas do not cover much of the land.

We present the map of land suitability assessment for pear trees using the MLCM in Fig. 1. It shows that the western and southern areas of the country have more suitable areas than do the northern and eastern regions, in which there are few suitable areas. In terms of percentage of suitable areas (S1, S2, S3) by province, Jeju-do has more suitable land than does any other province, with 57.43%. Chungcheongnam-do, Jeollanam-do, Gyeonggi-do, and Jeollabuk-do have suitable areas covering 33.90%, 25.72%, 23.59%, and 21.98% of their land, respectively, which is more than any of the others. In Gangwon-do, only 3.85% of the land is suitable, which is the least percentage-wise among all provinces.

We present the percentage of each grade per province according to the MLCM in Fig. 2. As is evident in Fig. 1 and 2, N1 land is predominant in all areas except Jeju-do. In Gangwon-do, in particular, the amount of N1 land is extremely high. S3 is the second most prevalent category in all areas except Gangwon-do. Generally, the rankings of each grade are consistent considering the results of the AHP over all areas.

Table 4. Classification results using the most-limiting characteristic method

Classification	Percentage
N2	5.51
N1	74.94
S3	13.30
S2	5.77
S1	0.48

In Fig. 3, we present comparisons between the amount of suitable land (grades S1, S2, and S3) in each province as a percentage of total land in South Korea according to the MLCM and the percentage of pear farms in each province in the 5 years we analyzed (1982, 1987, 1992, 1997, 2002, and 2007) or just in 2007 in each province (Do). The absolute difference between the percentage of suitable areas (S1, S2, S3) in each Do and the percentage of pear farms in each province in those 5 years is 40.62, which is bit smaller than the absolute difference between the percentage of suitable areas (S1, S2, S3) in each Do and the percentage of land covered by pear farms in each province in 2007, which is 45.30.

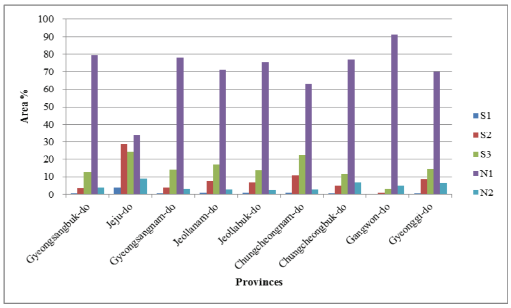

Fig. 2. The percentage of grid cells in each grade according to the MLCM.

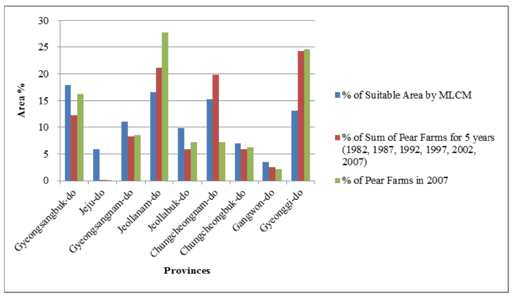

Fig. 3. Suitable areas (S1, S2, S3) in each province (Do) as a percentage of all suitable areas in South Korea according to the MLCM and pear farms in the 5 years we analyzed (1982, 1987, 1992, 1997, 2002, and 2007) as a percentage of the all pear farms in those 5 years, and the percentage of pear farms in each province against total pear farms in 2007.

Table 5. AHP results

Main factor	Weight	Variable	Weight
Soil and topographic factors	0.343		
		Soil texture	0.240
		Slope	0.202
		Drainage class	0.244
		Available soil depth	0.195
		Pebble content	0.119
Climate factor	0.657		
		Temperature during growing season	0.625
		Mean annual temperature	0.375

3.2. Pear classification by AHP

Weighted values given by the AHP analysis are presented in Table 5. The AHP results show that a weight of 0.343 was determined for soil and topographic factors, and a weight of 0.657 was given for climate-related factors, which means that the experts thought that the climate is relatively more important than are soil and topographic factors for growing pears. Among the variables involved in the climate factor, they set a high value for temperature during the growing season, which was regarded as very important for growing pears. Among variables related to soil and topographic factors, soil texture and drainage had relatively high values, whereas pebble content received a relatively low value.

Results of land area classification using the AHP method are presented in Table 6. The results of the AHP indicated that suitable areas (S1, S2, or S3) occupy most of the land, together accounting for 99.08% of all available land. In detail, S3, S2, and S1 occupy 23.11%, 33.69%, and 42.28% of the total land, respectively. Only 0.92% of the land is classified as N1, which means that the number of unsuitable areas is extremely small.

We present a map of land suitability assessment for pears according to the AHP method in Fig. 4. In general, in southern and western areas there are more suitable areas and in northeastern areas the degrees of suitability tend to decrease. However, compared with the results of the MLCM, much larger areas of suitable land are generally present. In detail, only Chungcheongbuk-do has 96% suitable land, whereas all other areas have more than 99% suitable land. Jeju-do, Jeollanam-do, Gyeongsangnam-do, and Chungcheongnam-do had 79.33%, 75.38%, 65.51%, and 59.80% of their land classified as S1, respectively, which are higher than in the other provinces.

Table 6. Classification results using the AHP method

Class	Percentage
N1	0.92
S3	23.11
S2	33.69
S1	42.28

The percentage of each land grade in each province according to the AHP is presented in Fig. 5. The ranks of each grade as determined by the MLCM were relatively consistent over all areas, but the ranks given by the AHP method are much more diverse in each area. We found that S1 was the most prominent ranking in Jeju-do, Gyeongsangnam-do, Jeollanam-do, Jeollabuk-do, and Chungcheongnam-do. In Gyeongsangbuk-do, S2 accounted for the largest percentage of land and in Gangwon-do, S3 land occupied a larger area than did land of other grades. N1 covered very little area overall.

We present comparisons between the amount of suitable land (S1, S2, and S3) in each province as a percentage of all suitable areas according to the AHP method and the number of pear farms in each

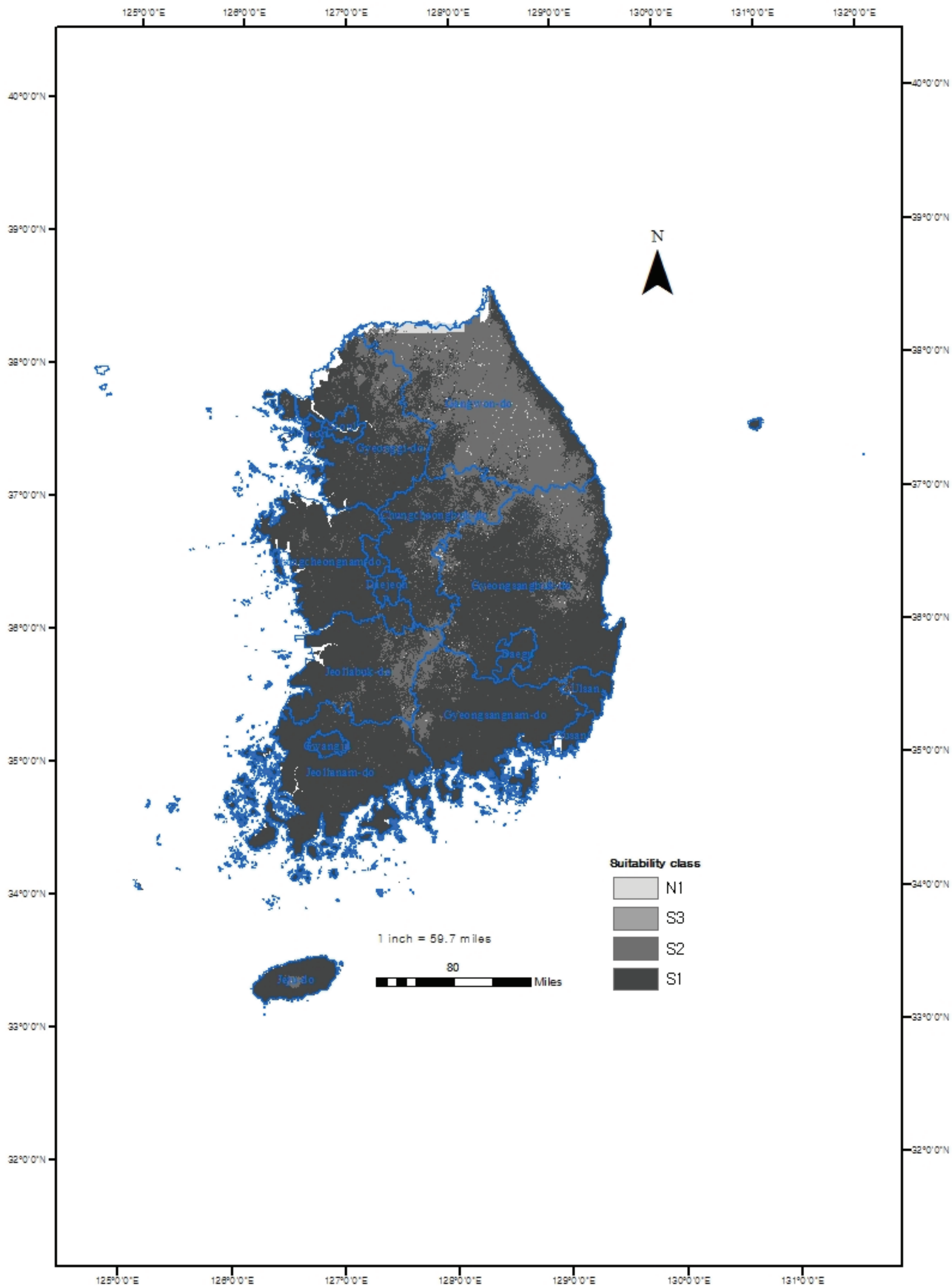

Fig. 4. Map of land suitability assessment for pear trees using the AHP method.

province for the 5 years studied (1982, 1987, 1992, 1997, 2002, and 2007) as a percentage of all pear farms in those 5 years or only in 2007 in Fig. 6. In Gyungsangnam-do, Jeollabuk-do, and Chungcheongbuk-do, the differences between the percentages of suitable areas as determined by the AHP method and the percentage of pear farms in the 5 years or in 2007 were not very high. The absolute differences between the percentage of suitable areas according to the AHP method and the percentage in the 5 years in each

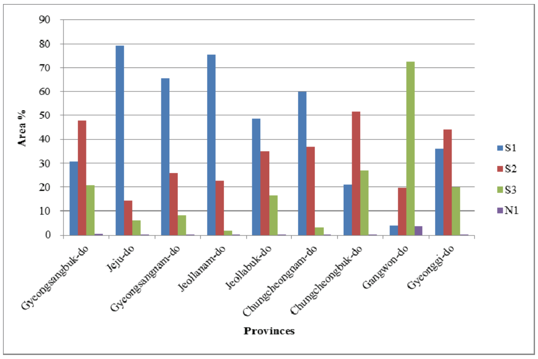

Fig. 5. The percentage of land in each grade according to the AHP method.

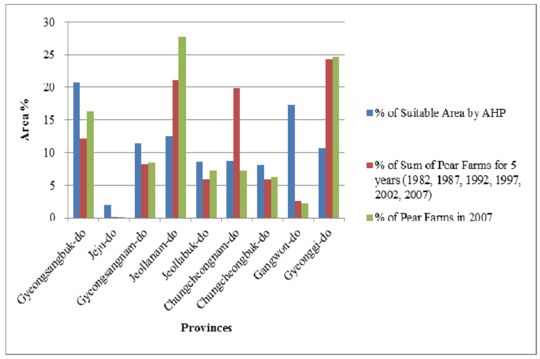

Fig. 6. The amount of suitable land areas (S1, S2, S3) in each province (Do) as a percentage of the total suitable land in the country according to the AHP, and the amount of pear farms in each province over the 5 years studied (1982, 1987, 1992, 1997, 2002, and 2007) as a percentage of the total pear farms in those 5 years, and only in 2007.

Do was 66.83, and the absolute difference between the percentage of suitable areas according to the AHP method and the percentage of pear farms in 2007 was 58.29.

In general, the degrees of suitability determined by the AHP method were much higher than those determined by the MLCM. Basically, the MLCM sets the worst value among all studied variables as the representative value for an area, so the methodology deems relatively few areas of land suitable as one limiting factor will determine the grade of an area. It is notable that the difference between the results of the two methods is so large in terms of suitable areas. The percentage of suitable areas (S1, S2, and S3) according to the MLCM was 19.55%, whereas 99.08% of land was classified as suitable according to the AHP method. In particular, only 0.48% of land was classified as S1 and 5.77% was classified as S2 by the MLCM, which are very small amounts. Such huge differences between the two methods could be interpreted as meaning that one of the methods is wrong if the true value is close to the other or that both results are not accurate if the true value is located somewhere between the two, in this case, something like the percentage of suitable areas being about 60%, which is mid-way between the percentages of suitable area given by the two methods (20% and 99%). So, it is beneficial to assess the results in light of real data, such as the number of pears yielded by a farm in one year.

Although we do not have real data on the number of pears yielded per farm per year, we have real data on pear farms in each area of the country (without the amount yielded by each farm) for 5 years (1982, 1987, 1992, 1997, 2002, and 2007) in each province, or “Do” (Table 3). To assess the accuracy of our methods, we compared the proportion of suitable areas (S1, S2, S3) in each province as determined by the two methods and the proportion of pear farms in each province in 5 different years (1982, 1987, 1992, 1997, 2002, and 2007) or just in 2007. We compared the difference between the suitable areas in each province as a percentage of all suitable areas according to each method and the proportion of pear farms in each province in the 5 years studied as a percentage of all pear farms in the country. The results show that the absolute difference between the two values according to the MLCM in all areas was 40.62%, and that by the AHP was 66.83%, which means that the MLCM results in each province can be regarded as more similar to the proportion of pear farms in each province based on real data. We also compared the difference between the percentage of suitable areas and the percentage of pear farms in 2007 in each area. The absolute difference according to the MLCM results in all areas was 45.30%, whereas that by the AHP was 58.90%. In both cases, the values of the absolute difference according to the MLCM were smaller, which means that the MLCM can be interpreted as more accurate in terms of proportional comparisons. This result can be regarded as a reference to compare the accuracy of the two methods based on the assumption that the more suitable areas for pears a province has, the more pear farms the province has. However, such an assumption may not always hold because, even if a province has a relatively large amount of land that would be suitable for cultivating pears, only a small area may be cultivated if other agricultural products are also regarded as suitable and more of the other products are cultivated.

IV. DISCUSSION

We also used information on 314 real pear farm locations and we checked the average degree of suitability based on a numeric rating of 0, 5, 10, 15, and 20 for N2, N1, S3, S2, and S1, respectively. With the MLCM method, the average value was 8.54, which means that the average value of real pear farms is in the marginally suitable (S3) zone, which is over 5 but less than 10. On the contrary, according to the AHP method, the average value was 19.69, which means that almost all pear farms were in highly suitable (S1) areas. Because we do not have any information on the yield or income of each farm, we cannot definitively say which result is more accurate. Instead, we can only assume that the average value for real farms for pear of around 20 according to the AHP method seems to be unreasonably high and the value of 8.54 given by the MLCM method is likely too low. The real field data with yield information per farm would be very useful for us to determine the accuracy of the results in future research.

Moreover, the weight values of 20, 15, 10, 5, and 0 for S1, S2, S3, N1, and N2 were based on the weight values for soil conditions, and we adapted the values for climate conditions based on discussions with relevant experts. However, the values did not necessarily coincide with real field data, so if the weight values can be further analyzed in light of real field data, the accuracy of the land suitability assessment can be enhanced.

In conclusion, the MLCM method can be regarded as a very strict method of assessing land suitability, and the AHP may produce relatively generous results. Therefore, for farmers who intend to grow pears in South Korea, it may be useful to reference both results and expect the suitability class to range from a low grade by the MLCM to a high grade by the AHP. Using the average of the two values to produce a land suitability assessment for any given area may be one useful decision making strategy. More detailed information on real field data, including information on yield or economic income, will make judging which method is more accurate easier. In this research, we used the two methods, MLCM or AHP, separately. Instead of using only one method, using both methods in a mixed fashion, like using the MLCM for soil conditions and the AHP for climate conditions, may be a viable alternative for future research.

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

적 요

GIS 기술은 다기준(multiple-criteria) 의사결정 기반으로 작물의 적지 평가를 가능하게 하고 있다. 본 연구에서는 남한지역을 대상으로 최대저해인자법(MLCM)과 분석적 계층화법(AHP)을 활용하여 배 과수의 적지를 평가하였다. 남한지역의 배 과수의 적지 등급 결과는 두 방법간에 큰 차이를 나타냈는데, MLCM 기법에서는 남한 면적의 19.55%에서 적지 등급(S1, S2 및 S3)로 구분된 반면에 AHP기법에서는 99.08%에서 적지로 구분되었다. 즉, MLCM기법은 적지 등급 결정에 매우 엄격한 반면에, AHP기법은 상대적으로 관대한 것으로 분석되었다. 다음으로 어떤 행정구역(도)에서 적지 등급으로 구분된 면적이 많으면

많을수록 더 많은 과수가 재배될 것이라는 가정 하에, 두 가지 방법으로 구분된 적지면적의 비율과 과거 5년 (1982, 1987, 1992, 1997 및 2002년) 및 2007년의 실제 배 재배 농장의 면적을 비교한 결과, MLCM기법에 의한 적지 등급의 결과가 더 정확한 것으로 분석되었다. 하지만, 이러한 가정이 항상 진실을 담보하는 것이 아니므로, 어떤 지역에서 배 과수의 재배를 계획하는 농가는 두가지 방법에 의한 적지평가 결과를 함께 참고해야 할 것이다. 더욱 정확한 결과를 얻기 위해서는 향후에 개별 배 농장에서 조사된 생산량과 수익자료를 추가하여 비교 분석할 필요가 있다.

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