한국농림기상학회지, 제21권 제4호(2019) (pISSN 1229-5671, eISSN 2288-1859)
Korean Journal of Agricultural and Forest Meteorology, Vol. 21, No. 4, (2019), pp. 286~296
DOI: 10.5532/KJAFM.2019.21.4.286

토양 및 기후정보 통합 최대저해인자법에 의한 복숭아와 포도의 적지 평가

김호정[1] · 구경아[2] · 심교문[1*]
[1]국립농업과학원, [2]한국환경정책평가연구원
(2019년 9월 11일 접수; 2019년 11월 21일 수정; 2019년 11월 25일 수락)

The maximum limiting characteristic method-based land suitability assessment for peaches (*Prunus persica*) and grapes (*Vitis vinifera L.*) using rasterized data of soil and climate on agricultural land in South Korea

Hojung Kim[1], Kyung-Ah Koo[2] and Kyo-Moon Shim[1*]
[1]*National Institute of Agricultural Sciences, Rural Development Administration, Wanju, Korea*
[2]*Environmental Policy Research Group, Korea Environment Institute, Sejong, Korea*
(Received September 11, 2019; Revised November 21, 2019; Accepted November 25, 2019)

ABSTRACT

Land suitability assessments have been a crucial issue for enhancing productivity in agriculture and conserving agricultural lands. Based on soil and climate information, land suitability assessment for peaches (*Prunus persica*) and grapes (*Vitis vinifera L.*) were conducted using the maximum limiting characteristic method (MLCM) in South Korea. In peaches, S1 (highly suitable) exists on 2.21% of the land, S2 (moderately suitable) on 19.20%, N1 (currently not suitable) on 12.07%, and N2 (permanently not suitable) on the remaining 66.52%. In grapes, 3.65% of the land is classified as S1, 17.98% as S2, 11.85% as N1 and 66.52% as N2. In both fruit trees, the results acquired from soil and climatic information were similar to those from soil information alone. The data also suggest that the grades by soil information were relatively low over the land. With the assumption that the more suitable area a province has, the more will be cultivated for the fruit trees, we compared the percentages of area for peach and grape farming per province with the results by MLCM, and suggested that some provinces with a small percentage of farm can be encouraged to plant more in suitable areas as dictated by MLCM for the species. In the near future, we plan to use an advanced method such as analytic hierarchy process (AHP) to conduct similar tests, in which having reference data of yields or benefits per farm can efficiently increase the accuracy of the measurements.

Key words: **Land suitability assessment, Maximum limiting characteristic method, Peach, Grape, Soil and climate information**

* Corresponding Author : Kyo-Moon Shim
(kmshim@korea.kr)

I. INTRODUCTION

The evolution of human society has played an important role in land use decisions, which have evolved from individual opinions to the processes of land-use planning (Brinkman and Young, 1976). With land-use planning, we can be valuably guided on decision-making that involves the use of land for managing environments to meet both human benefits and the conservation of natural land resources (Brinkman and Young, 1976; Beathley, 1995). Land evaluation assesses land performance for specific purposes and interprets various land aspects based on alternative land-use purposes (Brinkman and Young, 1976; Rossiter, 1996; Sonneveld *et al.*, 2010).

In many areas, there are various problems such as productivity loss and land degradation that can threaten the quality of human life (Barah, 2010; Bhagat, 2012; Zolekar and Bhagat, 2015). Land degradation is a particularly important factor for agricultural land-use planning because degraded lands cause the actual or potential loss of agricultural productivity. In South Asia and Sub-Saharan Africa where dense populations exist, land degradation has a greater impact on the economy (Eswaran *et al.*, 2001). For example, in Sub-Saharan Africa, nutrients are depleted as land degradation occur; specifically, it was reported that nitrogen was depleted at 22 kg/ha, phosphorus at 3 kg/ha, and potassium at 15 kg/ha annually (Stoorvogel *et al.,* 1993). Such land degradation resulted in huge losses of agricultural productivity and resultant negative impacts on the economy (Bojö, 1996; Henao and Baanante, 2006). Therefore, land suitability assessments, which are the process of assessing land performance for agricultural products, are required to solve such problems in agricultural land and enhance productivity (He *et al.*, 2011; Mu, 2006).

To conserve or recover degraded lands, and to enhance the productivity of peaches and grapes, land suitability assessments for these crops, which are economically important agricultural products, were conducted in South Korea based on climate and soil conditions. Historically, assessments for agricultural products in South Korea have utilized only one factor, either climate or soil (RDA, 2010; RDA, 2013). However, studies elsewhere have employed more factors, such as climate and topography, improving the accuracy of the assessments (Akinci *et al.,* 2013; Gool *et al.*, 2016). Thus, we assessed land suitability for the production of peach and grape crops using a combination of soil and climate conditions. Assessments based on a single factor − climate or soil condition - were also implemented to examine if a multi-factors approach improved the accuracy of the suitability assessments.

II. MATERIALS AND METHODS

2.1. Study areas

South Korea is located in the southern part of the Korean Peninsula and between latitudes 33° and 39° N and longitudes 124° and 130E°, with a total area of 100,032 square kilometers (KOSIS, 2006). One of the geographical features of South Korea is that mountains cover about 62% of the land, such that large areas are not arable lowlands. The climate of South Korea is hot and humid in the summer, cold and dry in the winter. South Korea has a short period of heavy precipitation in the summer influenced by the East Asian monsoon. While winter minimum temperatures can drop below -20℃ in the inland areas of the country, the maximum temperature in the summer exceeds 30℃ in most areas (USLC, 1990). The soils in Korea are classified as 6 orders, 14 suborders, 24 great groups, 65 subgroups and 375 soil series. The dominant soils in Korea are Inceptisols and Entisols. The Alfisols, Ultisols, Histosols and Mollisols are recognized, but are of small extent (RDA, 1985).

2.2. Peaches and grapes

In 2018, the cultivation area of peaches (*Prunus persica*) in South Korea amounted to around 21 thousand hectares, showing a steady increase since

Table 1. Soil conditions for the peach

Variable	S1	S2	N1
Soil texture	Clay loam, Silt clay loam, Sandy loam, Silt sandy loam, Clay	Gravelly soil	Sand, Gravelly sand
Drainage class	Moderately well	Well but too excessive, Moderately poor	Poor, Very Poor
Morphology	Fluvial plains, Alluvial fan, Valley, Diluvium	Hill, Foot slope of mountain, Lava plateau, Corrosion area	Fluvio-marine plains, Mountain, Cinder cone
Slope (%)	< 15	15-30	> 30
Available soil depth (cm)	> 50	20-50	< 20
Pebble contents (%)	< 35	≥ 35	≥ 35
Erosion degree (Loss of topsoil)	≤ 75%	> 75%	Gully

* S1: Highly suitable, S2: Moderately 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.).

Table 2. Soil conditions for the grape

Variable	S1	S2	N1
Soil texture	Clay loam, Silt clay loam, Sandy loam, Silt sandy loam, Clay	Gravelly soil	Sand, Gravelly sand
Drainage class	Moderately well	Well but too excessive, Moderately poor	Poor, Very Poor
Morphology	Fluvial plains, Alluvial fan, Valley, Diluvium	Hill, Foot slope of mountain, Lava plateau, Corrosion area	Fluvio-marine plains, Mountain, Cinder cone
Slope (%)	< 15	15-30	> 30
Available soil depth (cm)	> 50	20-50	< 20
Pebble contents (%)	< 35	< 35	≥ 35
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* S1: Highly suitable, S2: Moderately 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.).

Table 3. Climate conditions for the peach

Sub-factor	S1	S2	N1
Temperature during growing period (Apr. to Sept.) (℃)	$18.0 \leq x < 23.0$	$13.5 \leq x < 14.5$, $18.5 \leq x < 19.5$	$x < 13.5$, $19.5 \leq x$
Average temperature of a year (℃)	$11.5 \leq x < 15.5$	$6.5 \leq x < 7.5$, $11.5 \leq x < 12.5$	$x < 6.5$, $12.5 < x$
The lowest temperature (℃)	$-20 \leq x$	$-25 \leq x < -20$	$x < -25$

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

Table 4. Climate conditions for the grape

Sub-factor	S1	S2	N1
Temperature during growing period (Apr. to Sept.) (℃)	18.0 ≤ x < 22.0	16.0 ≤ x < 18.0, 22.0 ≤ s < 24.0	x<16.0, 24.0≤x
Average temperature of a year (℃)	11.0 ≤ x < 15.0	16.0 ≤ x < 18.0, 22.0 ≤ x < 24.0	x<9.0, 17.0<x
Temperature during the period of maturity (Aug.) (℃)	x < 26.0	26 ≤ x <30	x < 30.0
The lowest temperature (℃)	-18 ≤ x	-25 ≤ x < -18	x < -25

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

2008. Peach trees have a chilling requirement that require approximately 500 hours of chilling at a temperature range of 0 to 10°C. During the chilling seasons, key chemical reactions occur, which is followed by a quiescence period in which bud starts to grow as the temperature gets warm enough.

On the other hand, the grape (*Vitis vinifera L.*) is a fruit of the deciduous woody vine family, is cultivated over a long season, and is one of the most widely produced fruits around the world (OFA, 2017). Hot and dry weather conditions are preferred for cultivating grapes, which is mainly influenced by temperature, relative humidity, frost condition and rainfall (AF, 2015). In 2018, the cultivation area of grapes in South Korea amounted to around 11 thousand hectares, showing a slow decrease since 2001.

2.3. Land suitability assessments and orders

For the suitability assessments, we used the maximum limiting characteristic methods (MLCM) which assigns the worst-graded value among all variables as the representative grade for each site (Brinkman and Young, 1976). We also compared the percentage of suitable areas for each province (Dos) with the percentage of farm areas for peaches and grapes per province in 2006 to give insights into MLCM as a methodology that can be used to provide information regarding the ideal locations to plant more peaches and grapes.

FAO (Food and Agriculture Organization of the United Nations) provides land suitability orders which are either suitable (S) or not suitable (N). S is further classified into highly suitable (S1), moderately suitable (S2) and marginally suitable (S3), and N into currently not suitable (N1) and permanently not suitable (N2) (Brinkman and Young, 1976). The soil variables used in land suitability orders of peaches and grapes are soil texture, drainage class, morphology, slope, available soil depth, pebble cotents, and erosion degree (Table 1 and Table 2; NAS, 2016). For climate conditions, we used three or four subfactors that determine land suitability of both fruit trees: temperature during growing period, average temperature of a year, temperature during the period of maturity (grape only), and the lowest temperature (Table 3 and Table 4; NIHHS, 2010).

III. RESULTS

3.1. Climate and soil information

We used climate information gathered between 1981 and 2010, which was based on 30-meter grid cells (NIHHS, 2010) and soil information as a vector-based database with a map scale of 1:25000 (NAS, 2016), which is later transferred into raster map that can be matched with climate maps.

3.2. Peach classification

The results for peach classification by climate information were presented in Table 5. S1 exists on 41.40% of the land and S2 on 34.84%, which account for 76.24% of suitable land areas, while only 23.76% of the land was classified as non-suitable.

Classification results for peaches by soil information are presented in Table 6. 6.59% of the land was classified as S1 and 19.33% as S2, which cover 25.92% of the land as suitable areas. On the other hand, 4.23% of the land was classified as N1 and 69.85% as N2, which account for 74.08% of the total land area.

Table 5. Classification results for the peach by climate information

Class	Percentages
S1	41.40
S2	34.84
N1	23.76

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

Table 6. Classification results for the peach by soil information

Class	Percentages
S1	6.59
S2	19.33
N1	4.23
N2	69.85

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

The classification result for peach by both climate and soil information is presented in Table 7. 2.21% of the land was classified as S1 and 19.20% as S2, with a total of 21.41% of suitable areas. On the other hand, 12.07% is classified as N1 and 66.52% as N2.

We observed that the classification results by both soil and climate information was very similar to those from only soil information. In both results, the values of S2 and N2 were very similar while those of S1 and N1 were slightly varied. A potential reason for this is that the results from soil information were relatively downgraded than those by climate information in peach. However, we observed that northern areas such as Gangwon-do and Gyeonggi-do have relatively less suitable areas, and are likely to be influenced by the temperatures too.

Table 7. Classification results for the peach by soil and climate information

Class	Percentage
S1	2.21
S2	19.20
N1	12.07
N2	66.52

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

Table 8. Suitability classification for the peach according to each province

Province	S1	S2	N1	N2	S	N
Gyeongsangbuk-do	14.07	18.77	15.99	23.45	16.42	19.72
Jeju-do	0.89	3.94	0.55	1.79	2.42	1.17
Gyeongsangnam-do	18.05	12.92	3.15	12.63	15.49	7.89
Jeollanam-do	36.48	22.71	6.92	10.38	29.60	8.65
Jeollabuk-do	16.56	12.55	12.94	6.78	14.56	9.86
Chungcheongnam-do	9.56	17.39	11.73	5.89	13.48	8.81
Chungcheongbuk-do	0.07	4.29	13.77	8.77	2.18	11.27
Gangwon-do	3.76	1.29	14.78	21.75	2.53	18.26
Gyeonggi-do	0.56	6.14	20.17	8.56	3.35	14.36
Total	100	100	100	100	100	100

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable, N2: Permanently not suitable, S: Suitable area calculated by (S1+S2)/2, N: Non-suitable area estimated by (N1+N2)/2.

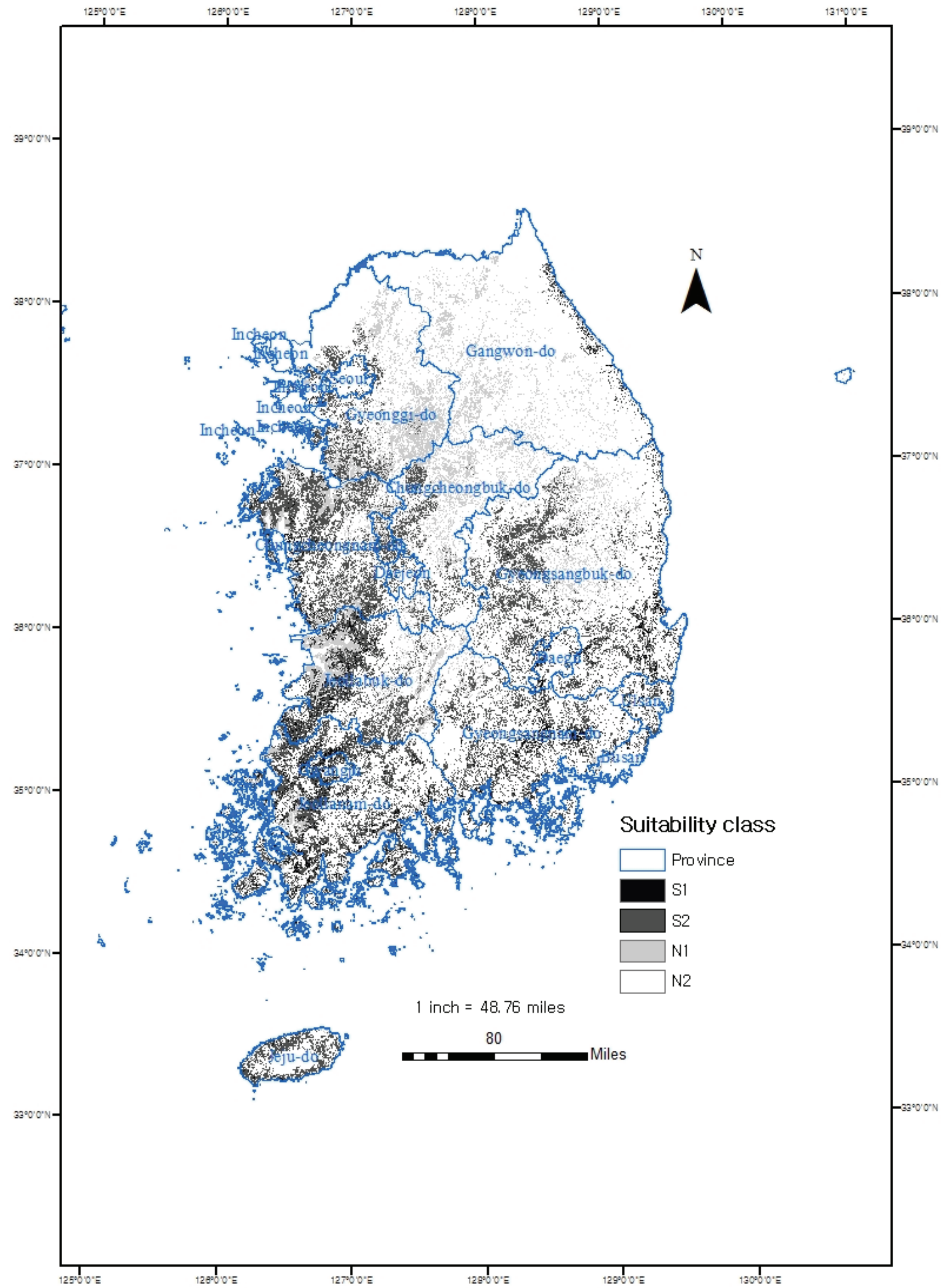

Fig. 1. Map of land suitability classification for peach trees generated using the soil and climate information.

The map of suitability classification for peach using both soil and climate information is presented in Figure 1, while suitability classification results for the peach, according to province, is presented in Table 8. According to these results, Jeollanam-do has the highest areas of S1 among all S1 areas in the country, while Gyeongsangnam-do, Jeollabuk-do and Gyeongsangbuk-do have relatively more S1 areas

Table 9. The total area (ha) and percentages of area for peach and grape farming according to province in 2016

Province	Peach		Grape	
	Area (ha)	% of Area	Area (ha)	% of Area
Gyeongsangbuk-do	6343	46.18	6447	56.82
Jeju-do	2	0.01	0	0.00
Gyeongsangnam-do	237	1.73	201	1.77
Jeollanam-do	575	4.19	167	1.47
Jeollabuk-do	951	6.92	595	5.24
Chungcheongnam-do	335	2.44	803	7.08
Chungcheongbuk-do	4066	29.61	1029	9.07
Gangwon-do	391	2.85	259	2.28
Gyeonggi-do	834	6.07	1846	16.27

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

than any other classification. As for S2, Jeollanam-do has the highest value, followed by Gyeongsangbuk-do, Chungcheongnam-do, Gyeongsangnam-do and Jeollabuk-do. On the other hand, Gyeongsangbuk-do has the highest N2 value among all regions in the country, while Gangwon-do has 21.75% of N2, closely followed by Gyeongsangnam-do and Jeollanam-do. With the combined values of N1 and N2 as non-suitable areas, Gyeongsangbuk-do has the highest value of 19.72% while Gangwon-do has 18.27%.

According to Table 9, Gyeongsangbuk-do shows the highest percentage (46.18%) of peach farming areas in 2016, and Chungcheongbuk-do follows it with 29.61%. According to our outcomes by MLCM, Gyeongsangbuk-do has 16.42% of all suitable areas (S1+S2). Although there is a difference between the percentage of actual farming areas and the suitable areas estimated by MLCM, the results by MLCM for Gyeongsangbuk-do was also relatively higher than other areas. On the other hand, Jeollanam-do, Gyeongsangnam-do, Jeollabuk-do and Chungcheongnam-do showed relatively high values of suitable areas, but the data depicted low percentage of area that are actually cultivated for peach. Therefore, it can be suggested that more peach may be cultivated in the suitable areas of these provinces. However, our 2016 data revealed that although Chungcheongbuk-do showed relatively high percentages for peach farm, our MLCM results were contradictory and showed a mere 0.07% of S1 areas and 4.36% of suitable areas.

3.3. Grape classification

In the case of grapes, the classification results by soil and climate information were very similar to

Table 10. Grape classification by climate information

Class	Percentages
S1	33.13
S2	43.07
N1	23.80

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable

Table 11. Grape classification by soil information

Class	Percentages
S1	6.59
S2	15.83
N1	7.72
N2	69.85

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable, N2: Permanently not suitable

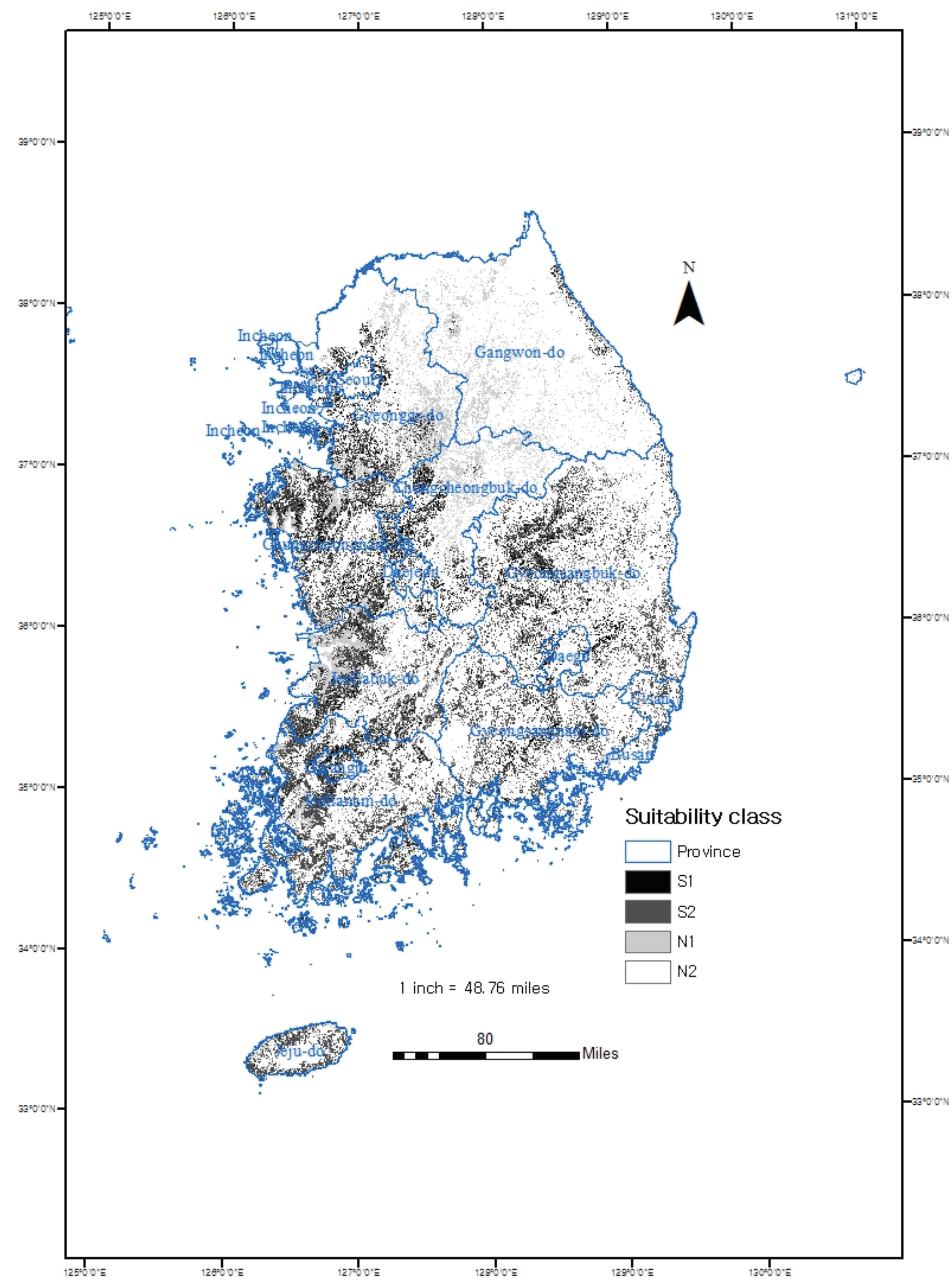

Fig. 2. Map of land suitability classification for grape trees generated using the soil and climate information.

those from soil information alone (Tables 10~12), similar to the peach. In terms of the percentage of suitable area (S), most provinces had suitable lands comprising greater than 10%, with the exception of Jeju-do, Gyeongsangnam-do and Gangwon-do that showed relatively less amounts of suitable areas.

As depicted in Table 9, Gyeongsangbuk-do has more areas of grape than any other region (56.82%),

Table 12. Grape classification by both soil and climate information

Class	Percentage
S1	3.65
S2	17.98
N1	11.85
N2	66.52

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable, N2: Permanently not suitable

with Gyeonggi-do, Chungcheongbuk-do and Chungcheongnam-do following at 16.27%, 9.07% and 7.08%, respectively. According to our MLCM results (Table 13), Chungcheongnam-do, Gyeongsangbuk-do and Gyeonggi-do have 17.20%, 16.78%, and 14.93% of all suitable areas, respectively, which are considered relatively high. Jeollabuk-do, Jeollanam-do and Chungcheongbuk-do have 12.40%, 11.96% and 11.05% of all suitable areas. Gyeongsangbuk-do, Gyeonggi-do, Chungcheongbuk-do and Chungcheongnam-do showed relatively high percentages in both 2016 data (Table 9) and the MLCM results (Table 13). However, Chungcheongnam-do and Chungcheongbuk-do showed relatively high percentage only in MLCM. Therefore, our analyses suggest that more areas can be suitable for cultivating grapes in these two provinces.

IV. DISCUSSION

The results obtained for both fruit trees using a combination of soil and climate data were similar to those obtained using the soil data alone, and the reason seems to be that the grades obtained via soil information were relatively lower than the ones obtained from climate data over the county. The MLCM assigns the worst grade among all grades in each site assuming that one of the worst characteristics determines the grade more severely. Such assumptions can be reasonable but cannot be adapted for every case, so more diverse methods, such as AHP (Akinci *et al.*, 2013) can be tested in both fruits, and comparing the MLCM estimations with the reference data of real crop totals per farm area will be beneficial to check for the accuracy in further study.

Regarding peaches, when only the condition of climate was considered, roughly western and southern areas are regarded as suitable areas except only areas of Gangwon and east of Gyunggi-do, and when only the condition of soil we could observe suitable areas in western regions but mostly unsuitable are shown. Thus, if the condition of soil can be updated in the areas where the condition of climate is ideal and that of soil is bad, such areas would be changed from

Table 13. Suitability classification results for grapes according to each province

Province	S1	S2	N1	N2	S	N
Gyeongsangbuk-do	23.22	10.35	21.11	23.45	16.78	22.28
Jeju-do	0.12	1.27	3.81	1.79	0.70	2.80
Gyeongsangnam-do	8.18	5.28	12.87	12.63	6.73	12.75
Jeollanam-do	10.36	13.56	22.05	10.38	11.96	16.22
Jeollabuk-do	10.97	13.83	12.74	6.78	12.40	9.76
Chungcheongnam-do	23.39	11.00	15.65	5.89	17.20	10.77
Chungcheongbuk-do	9.78	12.32	3.83	8.77	11.05	6.30
Gangwon-do	1.22	15.3	1.47	21.75	8.26	11.60
Gyeonggi-do	12.76	17.09	6.47	8.56	14.92	7.52
Total	100	100	100	100	100	100

* S1: Highly suitable, S2: Moderately suitable, N1: Currently not suitable, N2: Permanently not suitable, S: Suitable area calculated by (S1+S2)/2, N: Non-suitable area estimated by (N1+N2)/2.

unsuitable areas into suitable areas.

Regarding grapes, once we consider the condition of climate, roughly eastern areas of Gyunggi-do and Gangwon-do were shown as unsuitable areas. If only the soil condition is considered, the unsuitable areas cover all of the nation roughly, but relatively in the western regions we observed suitable areas. Same as with peaches in the areas where the climate is ideal but the soil condition is relatively poor, an updated soil condition would make the regions suitable.

Heuk-to-ram, a web portal site providing data on soil and environments is constructed by the interpretation of aerial photos, field survey and classification, investigation of representative soil, and building soil maps according to the guide on soil research that describes how to investigate and analyze soil. If we could develop better and updated technologies in capturing aerial photos and manipulating remote sensing and GIS, we could have more refined materials-related soil information to build more accurate soil maps, which will increase the accuracy of suitability map.

적 요

본 논문에서는 남한지역을 대상으로 토양학적 그리고 기후학적 적지 기준을 통합하여 최대저해인자 방법으로 과수 2종(복숭아와 포도)에 대해서 재배적지를 구분하였다. 복숭아는 최적지 2.21%, 적지 19.21%, 가능지(저위생산지 포함) 12.07%, 부적지 66.52%로 구분되었고, 포도는 최적지 3.65%, 적지 17.98%, 가능지(저위생산지 포함) 11.85%, 부적지 66.52%로 구분되었다. 토양과 기후 조건의 통합에 의해 구분한 복숭아와 포도의 적지는 토양 조건만으로 구분한 적지와 유사한 것으로 분석되었고, 토양 조건에 의한 구분한 적지(최적지 포함) 면적이 기후 조건에 의해 구분한 면적보다 적은 것으로 분석되어서 토양 조건이 적지구분의 저해인자로 확인되었다. 어떤 행정구역(도)에서 적지(최적지 포함)로 구분된 면적이 많으면 많을수록 더 많은 과수가 재배될 것이라는 가정 하에, 행정구역별 복숭아와 포도의 실재 재배면적 비율과 토양 및 기후 조건 통합의 최대저해인자법에 의해 구분한 적지면적과 비교하였을 때, 실재 과수 재배면적의 비율이 적은 행정구역에서는 해당 과수의 재배면적 확대를 고려할 필요가 있을 것이다. 다만, 과수 적지구분의 정확도 향상을 위해서는 분석적 계층화법(AHP)과 같은 개선된 방법과 농장단위의 과수 생산량과 수익자료를 추가하여 비교 분석할 필요가 있다.

ACKNOWLEDGEMENT

This study was carried out with the support of the “Research Program for Agricultural Science & Technology Development (Project No. PJ01000701 & PJ01329001)”, National Institute of Agricultural Sciences, Rural Development Administration, Republic of Korea.

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