GIS-BASED CROP SUPPORT SYSTEM FOR COMMON OAT AND NAKED OAT IN CHINA

Fan Wan[1], Zhen Wang[1], Fengmin Li[1], Huhua Cao[2], Guojun Sun[1,*]

[1] *MOE Key Laboratory of Arid and Grassland Ecology, School of Life Science, Lanzhou University, Lanzhou, Gansu Province, P.R. China 730000*

[2] *Department of Geography, University of Ottawa, Ottawa, Ontario, Canada K1N 6N5*

[*] *Corresponding author, Lanzhou 730000, Gansu Province, P.R. China, E-mail: sungj@lzu.edu.cn*

Abstract: The identification of the suitable areas for common oat (Avena sativa L.) and naked oat (Avena nuda L.) in China using Multi-Criteria Evaluation (MCE) approach based on GIS is presented in the current article. Climate, topography, soil, land use and oat variety databases were created. Relevant criteria, suitability levels and their weights for each factor were defined. Then the criteria maps were obtained and turned into the MCE process, and suitability maps for common oat and naked oat were created. The land use and the suitability maps were crossed to identify the suitable areas for each crop. The results identified 397,720 km^2 of suitable areas for common oats of forage purpose distributed in 744 counties in 17 provinces, and 556,232 km^2 of suitable areas for naked oats of grain purpose distributed in 779 counties in 19 provinces. This result is in accordance with the distribution of farming-pastoral ecozones located in semi-arid regions of northern China. The mapped areas can help define the working limits and serve as indicative zones for oat in China. The created databases, mapped results, interface of expert system and relevant hardware facilities could construct a complete crop support system for oats.

Keywords: common oat, naked oat, multi-criteria evaluation, GIS; spatial database

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1. INTRODUCTION

Agriculture is the foundation of the national economy in China. Deterioration of ecological environment caused by poor management and unsustainable use of the natural resources has become a serious impediment to agricultural development particularly noticeable in the west of the country. Because of the tolerance to infertile, arid and salt environment, cultivation of common oat (*Avena sativa L.*) and naked oat (*Avena nuda L.*) can achieve the harmony and consolidation of production and improvement of the environment (Wang et al., 2006). Besides, common oat and naked oat have high nutritional values (CAMS, 1991; Zhang, 2006) and could be used for both grain and forage purpose. In China naked oat varieties dominate the cultivation of oat, particularly in the semi-arid farming-pastoral areas located northwest and northeast of the country, for the purpose of both grain and forage use. Only in some high-elevation regions in northwest and southwest plant common oat, generally for forage use (Li et al., 2007). It has become the main forage cultivated in the pasturing areas in west China to deal with the shortage of forage (Hou, 2003; Xu, 2003).

The identification of the suitable areas is essential to agricultural research and development (Corbett, 1996), it is an introduction for the future cultivation and programming of certain crops. Thus, in this study the suitable areas for common oat and naked oat in China should be identified. These tasks would provide visual guidance for the cultivation and the layout planning of oats in the future.

Suitable areas for crops are determined by evaluation of the climate, soil and topographical characteristics. Many variables and their criteria are involved in the analysis. Geographic information systems (GIS) are best suited for handling spatial data, with due consideration for the spatial variability for an efficient time and cost-effective evaluation (Ahamed et al., 2000). GIS has been applied in crop suitability evaluation in recent years (Gao, 2000). At present, Multi-criteria evaluation (MCE) has received renewed attention within the context of GIS-based decision-making (Pereira and Duckstein, 1993).It could be understood as a world of concepts, approaches, models and methods that aid an evaluation (expressed by weights, values or intensities of preference) according to several criteria. The integration of MCE problems within GIS could give more functionality to the user (Carver, 1991) and could help users to improve decision making processes. This method has been used in searching the best area for an infrastructure (like a plant, a commerce, etc.) and it has been illustrated as a powerful approach to land suitability assessments (Joerin et al., 2001).the application of GIS-based MCE in identify suitable areas for crops or fruit trees in a regional scale has been reported (Ceballos-Silva et al., 2003; Qiu et al., 2005).

However, the relevant research in identification of suitable areas for a certain crop such as oats in China hasn't been conducted. The objectives of this study were: (1) to establish the national space database of climate, topography and soil; (2) to research the suitable areas of common oat and naked oat within GIS and MCE approach at national scale, provincial scale and county scale in China.

2. METHODS

2.1 Establish of spatial databases

Climate data was obtained from China Meteorological Administration (CMA). The recorded years were 1970-2002. The variables selected were annual accumulated temperature, maximum temperature, minimum temperature, precipitation and sunlight duration. The climate data were obtained as point data, an interpolation procedure was conducted to estimate the spatial distribution of each climate variable. These works were conducted within the Ordinary Kriging model in the ArcGIS environment. Albers coordinate system was used, the spatial resolution was 1000m per pixel. The interpolated maps of accumulated temperature, maximum and minimum temperature were corrected by elevation (Corbett, 1996). First, regression models were carried out using temperature and altitude values from stations to get the temperature lapse rates (TLR) for each of the three factors, and then applied to each pixel of the interpolated temperature maps. The Mean Relative Error (MRE) of before and after adjust by elevation was calculated.

National digital contour map at the scale of 1:250 000 was obtained from the State Bureau of Surveying and Mapping. We use this contour data to create Digital Elevation Model (DEM) within ArcGIS, the process was contours→ TIN→ lattice → DEM. The slope and elevation information were obtained from the DEM. The Albers coordinate system was used, the spatial resolution was 1000m per pixel.

Soil characteristics were taken from digital Soil Type Maps (from ISSCAS) using a scale of 1:1 000 000. Sampling points was created, the total number of points were 99034. The information of soil texture and soil pH was obtained from soil type. Then the soil texture point data and the soil pH point data were interpolated into grid maps within ArcGIS. The Albers coordinate system was used and the spatial resolution was 1000m per pixel.

Land use information was taken from the digital land use maps of China (from Environmental and ecological Science Data Center for West China,

2000) at a cell size of 1000m. The land use type of urban use, residential areas, mining, water bodies and desert were excluded from the analysis as the non-suitable areas for crop cultivation.

2.2 MCE process for suitable areas of oats

The first phase of MCE consisted of the establishing of the relevant criteria for the analysis. By means of expert opinion and literatures, it was revealed that Accumulated Temperature, Maximum Temperature, Minimum Temperature, Precipitation, Sunlight Duration, Soil Texture, Soil pH, Elevation and Slope were the relevant factors for common oat and naked oat (Dong et al., 1994). Suitability levels for each of the factors were defined, these levels were used as a base to construct the criteria maps. According to the experts' opinion and the literatures, a specific suitability level per factor for naked oat and common oat were defined (Tables 2 and Table 3). Standardized factor maps were then constructed for common oat and naked oat from the interpolated maps of the factors. Constraint maps including urban use, residential areas, mining, water bodies, and desert were also made.

Table 2. Suitability level per factor for common oat

Factor	Level of suitability				
	Very high	High	Medium	Low	Very low
Accumulated temperature (◦C)	1400-2700	1000-1400 or 2700-3500	800-1000 or 3500-4000	500-800 or 4000-4700	<500 or >4700
Precipitation (mm)	450-650	400-450 or 650-800	350-400 or 800-1000	280-350 or 1000-1200	<280 or >1200
Max Temp (◦C)	14-19	19-21 or10-14	21-23 or 8-10	23-25 or 6-8	>25 or <6
Min Temp (◦C)	2-7	-1-2 or 7-9	-3--1 or 9-11	11-14 or-4--3	<-4 or >14
Sun duration (h)	>2400	2100-2400	1900-2100	1700-1900	<1700
Soil texture	Loam	Sandy loam	Sandy clay loam	Other class	Sand or clay
Soil pH	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.0	<5.5 or >9.0
Elevation (masl)	2000-3400	3400-3700 or 1500-2000	1000-1500 or 3700--4000	4000-4500	>4500 or <1000
Slope (%)	0-3	3-8	8-15	15-25	>25

Table3. Suitability level per factor for naked oat

Factor	Level of suitability				
	Very high	High	Medium	Low	Very low
Accumulated temperature (◦C)	2400-3500	2000-2400 or 3500-3900	3900-4300 or 1500-2000	1000-1500 or 4300-4700	<1000 or >4700
Precipitation (mm)	420-600	350-420 or 600-750	750-1000	250-350	<250 or >1000
Max Temp (◦C)	17-20	20-23 or 14-17	23-25 or 12-14	25-27	>27 or <12
Min Temp (◦C)	4-7	2-4 or 7-9	0-2 or 9-11	-2-0 or 11-14	<-2 or >14
Sun duration (h)	>2400	2100-2400	1900-2100	1700-1900	<1700
Soil texture	Loam	Sandy loam	Sandy clay loam	Other class	Sand or clay
Soil pH	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.0	<5.5 or >9.0
Elevation (masl)	1400-2200	1000-1400 or 2200-2500	<1000 or 2500-2700	2700-3000	>3000
Slope (%)	0-3	3-8	8-15	15-25	>25

Pair-wise comparison matrixes were made to get the weights of each factor for common oat and naked oat. The comparison concerns the relative importance of the two criteria involved in determining the suitability of the stated objective. This method use a scale with values from 1/9 to 9 to rate the relative preferences of the two criteria. In this study, factors were rated according to the opinion of crop experts from the Academy of Agricultural Sciences of Neimenggu and the Dry Farming Research Center of Dingxi.

Once the factors and constraints maps have been obtained, and the weights of each factor were calculated, the next step was to multiply each factor map by its weight and then sum the results. These works were conducted with the Weighted Overlay module in the ArcGIS environment. Next the summed map was overlaid with the Constraint maps to erase the non-suitable areas for crop cultivation, then the suitability map which has values in the same range as the standardized factor maps was produced.

Finally, the land use map and the maps of suitable areas for common oat and naked oat were crossed respectively. In this way, we obtained useful information concerning the spatial distribution of several suitability levels, according to Land use information.

3. RESULTS

3.1 Adjust of interpolated temperature maps by elevation

For accumulated temperature, the temperature lapse rates (TLR) was 1.12626 (◦C/m^{-1}), R^2= 0.57; for maximum temperature, the TLR was 0.0043 (◦C/m^{-1}), R^2= 0.88; for minimum temperature, the TLR was 0.0036 (◦C/m^{-1}), R^2= 0.75. The Mean Relative Error (MRE) between the measured (Z_{oi}) and the simulated value (Z_{ei}) of before and after adjust by elevation was calculated using the following formula (1) and the results showed in table 5.

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Z_{oi}-Z_{ei}}{Z_{oi}}\right| \tag{1}$$

Table 5. Mean relative errors (MRE) results of before and after adjust

	Maximum temperature	Minimum temperature	accumulated temperature
Before adjust	0.0438	0.4694	0.1160
After adjust	0.0279	0.0502	0.0667

According to table 5, the Mean Relative Error of interpolation much decreased after adjusted by elevation. Therefore the adjusted temperature maps were used to obtain the standardized factor maps.

3.2 MCE process for common oat

Weights of factors for common oat were calculated based on the Pair-wise comparison matrixes. The most important factors for common oat were: Accumulated Temperature (0.3078), Precipitation (0.2732), and Elevation (0.1441); Minimum Temperature (0.0779), Maximum Temperature (0.0745) and Sunlight Duration (0.0536) followed; Soil pH (0.0263), Soil Texture Class (0.0255) and Slope (0.0171) were the factors with the least importance. The consistency ratio was 0.04, considered acceptable. Once the standardized factor maps (Fig.1) and the weights per factor were obtained, the MCE was carried out and the map of suitable areas for common oat was obtained, then it was overlaid by the provincial boundaries to facilitate observation of the map (Fig. 2).

According to Fig. 2, Very high suitability areas were located in some mountain areas in Neimenggu, Hebei, Shanxi, Shaanxi, Gansu, Ningxia, Qinghai, Sichuan, Xinjiang and Xizang provinces. These areas generally had enough sunlight, cool weather, and without drought.

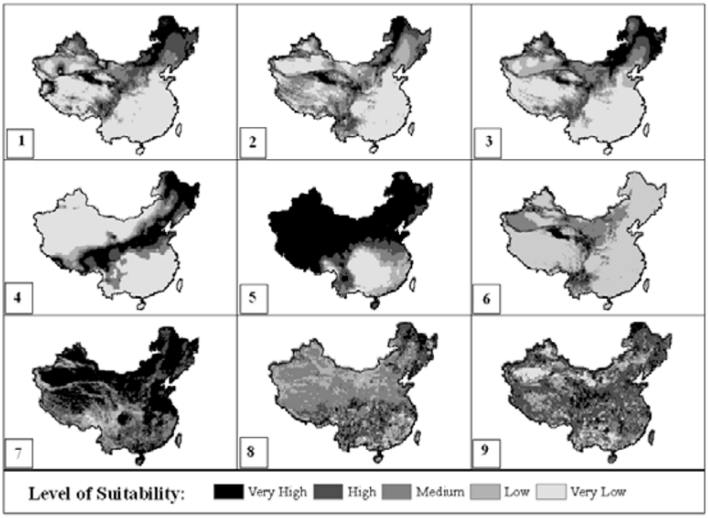

Fig.1: Factor map for common oat, including suitability levels for each factor. 1= Accumulated temperature, 2= Maximum temperature, 3= minimum temperature, 4= Precipitation, 5= Sunlight duration, 6= Elevation, 7= slope, 8= Soil pH, 9= Soil texture class.

The suitability map and the land use map were crossed and the extent of each suitability level per land use class was calculated (Table 6). The result identified

19,343 km^2 with very high suitability level and 378,377 km^2 with high suitability level in Dryland, these areas which totaled 397,720 km^2 can be considered as the best areas for common oat cultivation.

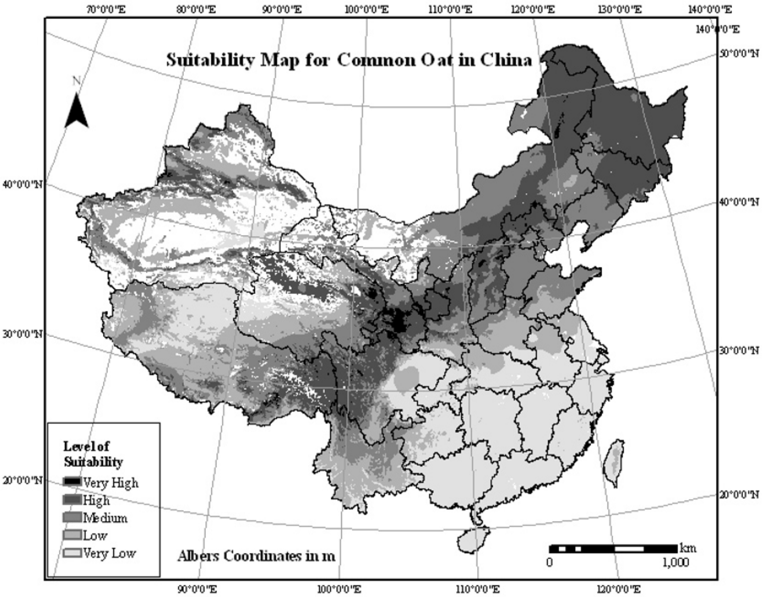

Fig.2: Suitability map for common oat in China.

Table 6. Result of crossing the suitability map for common oat and land use map.

Land use	Suitability level				
	Very high	High	Medium	Low	Very low
Pf	155[a]	19892	27180	66432	353581
Dl	19343	378377	467655	326092	237441
Fl	40811	555173	188228	181954	463201
Sh	6301	91404	72728	79433	137201
Sp	4435	68990	62218	80716	324528
Hg	24255	360558	478059	274141	110051
Mg	24088	328421	424708	271086	143043
Lg	6816	106017	321726	213171	72589
Sa	2	30715	25871	32931	17344
Ml	309	49346	17657	5677	517
Bl	0	33127	24330	20485	765

[a] *Units are in square kilometers (km^2). Pf = Paddy field, Dl = Dry land, Fl = Forest land, Sh = Shrub land, Sp = Sparse forest, Hg = High-coverage grassland, Mg = Moderate-coverage grassland, Lg = Low-coverage grassland, Sa = Saline-alkaline land, Ml = Marshland, Bl = Bare land.*

After overlaying the results with the province and county boundaries, suitability maps for common oat in each province and each county were obtained. 744 counties in 17 provinces were identified as potential areas for planting common oat, and their areas were calculated. Suitable areas per land use type for each province were shown in table 7, according to the result, Heilongjiang province has a largest potential area for common oat located in Dry land, Gansu, Jilin and Neimenggu province followed.

Table 7. Suitable areas for common oat in each province, take Gansu, Heilongjiang, Jilin, Neimenggu and Xinjiang province for example.

Province	Land use										
	Pf	Dl	Fl	Sh	Sp	Hg	Mg	Lg	Sa	Ml	Bl
Gansu	1	58064	17977	2868	3942	31659	32960	23448	35	494	62
Heilongjiang	10511	140498	169378	8746	30151	36206	5774	1702	2198	23194	10
Jilin	8147	52815	65839	1480	6394	2880	1306	262	1570	2269	72
Neimenggu	403	51724	138292	20227	5391	111403	49708	11976	1434	18344	48
Xinjiang	0	2505	11703	888	618	59478	41516	31496	53	928	1180

3.3 MCE process for naked oat

For naked oat, the weights of each factor were as follows: Accumulated Temperature (0.3124), Precipitation (0.2827), Minimum Temperature (0.0920), Maximum Temperature (0.0888), Elevation (0.0766), Sunlight Duration (0.0717), Soil pH (0.0289), Soil Texture (0.0285) and Slope (0.0184). The consistency ratio was 0.04, considered acceptable. Once the standardized factor maps (Fig.3), the constraint maps and the weights per factor were obtained, the MCE was carried out and the maps of suitable areas for naked oat were obtained (Fig. 4).

According to Fig.4, very high suitability areas were located in some areas in Heilongjiang, Neimenggu, Jilin, Hebei, Shanxi, Shaanxi, Gansu, Ningxia and Xinjiang provinces.

The suitability map and the land use map were crossed and the extent of each suitability level per land use class was calculated (Table 8). The result identified 245,509 km^2 with very high suitability level and 310,723 km^2 with high suitability level in Dryland, these areas which totaled 556,232 km^2 can be considered as the best areas for naked oat cultivation.

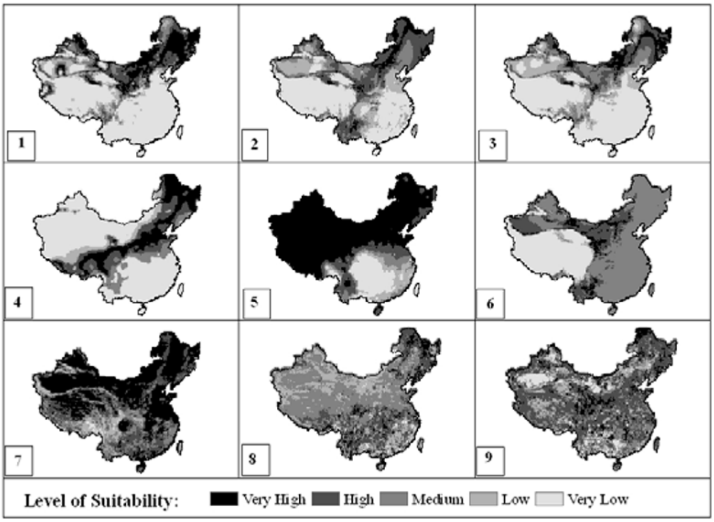

Fig.3: factor maps for naked oat, including suitability levels for each factor. 1= Accumulated temperature, 2= Maximum temperature, 3= minimum temperature, 4= Precipitation, 5= Sunlight duration, 6= Elevation, 7= slope, 8= Soil pH, 9= Soil texture class.

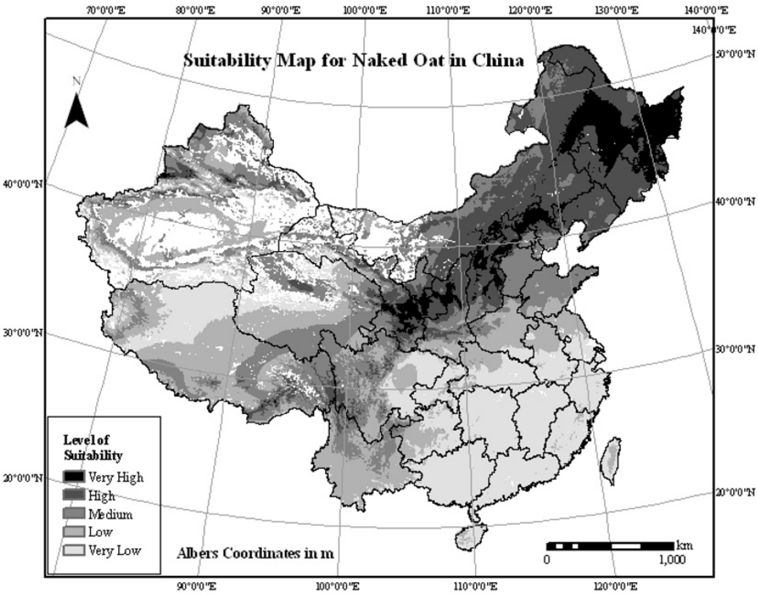

Fig.4: Suitability map for naked oat in China.

Table 8. Result of crossing the suitability map for naked oat and land use map.

Land use	Suitability level				
	Very high	High	Medium	Low	Very low
Pf	12993[a]	21067	15156	81991	336033
Dl	245509	310723	338309	319747	214620
Fl	135534	434264	202782	240968	415819
Sh	28152	60325	67241	103576	118773
Sp	18348	63315	53685	107614	297925
Hg	60293	278848	405556	389848	112519
Mg	45193	254621	339814	355209	195800
Lg	17802	151231	269084	159064	122605
Sa	2057	25258	36966	39894	2688
Ml	16185	39631	11952	5086	652
Bl	7	6285	54738	15819	1839

[a] *Units are in square kilometers (km^2).*

According to Ministry of Agriculture of the PRC (www.agri.gov.cn, 2005), the area cultivated with naked oat in China was approximately 2,800 km^2, and most of the naked oat production areas were located in Dryland. However, our results showed 556,232 km^2 considered as very high and high suitability areas for that crop in Dryland. In China, many oat production areas were located in Saline-alkaline land, for example, oats were planted in Baicheng in Jinlin province for the amelioration of the Saline-alkaline soil. Our result also identified 27,315 km^2 as suitable areas for naked oat in Saline-alkaline land (Table 8).

After overlaying the results with province and county boundaries, suitability maps for naked oat in each province and each county were obtained. 779 counties in 19 provinces were identified as potential areas for planting naked oat, and their areas were calculated. Table 9 showed the suitable areas per land use type for each province, according to this result, Heilongjiang province has the largest suitable area for naked oat located in Dry land, Neimenggu, Jilin and Gansu province followed.

Table 9. Suitable areas for naked oat in each province, take Gansu, Heilongjiang, Neimenggu and Xinjiang province for example.

Province	Land use										
	Pf	Dl	Fl	Sh	Sp	Hg	Mg	Lg	Sa	Ml	Bl
Gansu	7	63532	16898	2125	3372	13780	19387	33504	163	114	1042
Heilongjiang	11045	144930	167318	8792	30122	38251	6496	2453	2629	23660	10
Jilin	8792	71261	72362	1824	8747	5882	3482	1220	7321	3953	104
Neimenggu	657	89649	123564	33928	6931	202388	128404	46023	8621	25363	1014
Xinjiang	26	8057	2600	933	787	12681	11002	50111	67	71	1424

4. DISCUSSION

In this research the spatial data input, extraction, analysis and visualization functions of GIS were used to establish the national spatial database of climate, topography and soil. The correction of interpolated temperature maps by elevation could improve the accuracy of our result. These could be useful for other researchers to interpolate different climate factors in China. MCE procedure in this research was useful to evaluate the suitable areas for certain crops. In this MCE, the factors were selected based on agronomic knowledge of local experts and reviews of existing literature. Factor maps should be independent and the expert opinion was important for the definition of suitability level. Pair-wise comparison matrixes in the context of Analytical Hierarchy Process were made to obtain the weights and confirmed to be a useful approach in the decision-making process. Crossing of identified suitability maps with the land use information was important. Land use information was used not only for the elimination of unsuitable land use types, but also for constraining the result in the suitable land use types and minimizing the conflicts over land use. The introduction of administrative boundaries in this research was a useful approach that allowed us to present our results at national, provincial and county scales. This three-scale result presentation can provide general alternatives to agricultural land management of specific crops and varieties, being useful to different decision-makers such as local farmers, local government and the central government.

Furthermore, the feedback process of checking the results by local agronomic experts was involved, because results could be adjusted in light of their experience.

The identified suitable area for common oat and naked oat showed a zonal trend from southwest to northeast of China, this corresponds with the actual distribution of existing oat plantation sites. Besides, we found that the suitable area for common oat and naked oat is roughly consistent with the distribution of farming-pastoral ecotone in northern China (CAAS, 1984; Zhao et al.，2002). This result has demonstrated common oat and naked oat as the appropriate crops for agricultural production as well as for the Grain-for-Green process in the semi-arid regions of China.

However, the identified variety-suitable areas were proposed at a theoretical maximum, the microclimate and microtopography of the specific areas should be considered in the actual production. Decision-making process to select adequate crop patterns could be based on other issues such as: production supports (by local and federal governments), marketing, technological level, economic evaluation, in addition to local cultural traditions, which are highly important also.

5. CONCLUSIONS

In this research, we applied the MCE approach to identify suitable areas for common oat with forage purpose and naked oat with grain purpose within a GIS environment. The results confirmed that the methodology used was adequate to construct and integrate spatial databases of climate, soil, topography and land use. The interpolated factor maps of temperature, precipitation, sunlight duration, elevation, slope, soil pH, soil texture class and land use information were crucial in the identification of suitable areas for oat-crop production. The results were presented at national, provincial and county scales. The involvement of local crop expert opinion allowed us to generate reasonable delineating conditions and to obtain reliable and consistent results. Expert system based on the research results will be constructed and connected with the internet to facilitate the work of decision-makers and farmers.

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