Design of the Spatial Sampling Scheme for Estimating the Cultivation Area of Garlic and Onion Using Satellite-Based and Unmanned Aerial Vehicle Remotely Sensed Data

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ABSTRACT

Garlic and onion are the most important vegetable crops in Korea. The accurate estimation of cultivation area for garlic and onion acreage is critical to predict the production of vegetable crops, adjust agricultural planting plan and ensure an effective supply of farm products. However, the plots cultivated with garlic and onion are very fragmentary and dispersive because the cross cropping commonly occurs in the two crops. Therefore, it is very difficult to establish the accurate identification of garlic and onion using satellite-based remotely sensed images alone. In case of tracking Hapcheon Gun, Korea as the sampling site, objective of this study was to formulate a spatial sampling scheme through combining satellite-based, unmanned aerial vehicle (UAV) remotely sensed images and the stratified sampling method for improving the estimated accuracy to cultivation area of garlic and onion. The results are shown that there was almost no classification error, when UAV remotely sensed image was used to retrieve the cultivation area of garlic and onion. The error found in the two crops classification using Rapid Eye satellite-based images, and the classification error for garlic was the larger than that of onion. The variance for cultivation area of garlic and onion within each stratum can be significantly decreased, when the proportion of the cultivation area for two crops is accounted for one sampling unit. It was observed that the required sample size for meeting the designed extrapolation accuracy decreased with the stratification number of the sampled population. Comprehensively considering population extrapolating accuracy, sampling survey cost and rationality, 10 strata was the optimum stratification number. It was appeared that the spatial stratified sampling scheme combining satellite-based and UAV remotely sensed images had a high accuracy and stability for estimation of cultivation areas for the two crops, because both the relative error and CV of population extrapolation using this scheme was less than 10%.

Keywords: Spatial sampling, UAV, Remote sensing

Results of population extrapolation and error estimation for garlic acreage in the study area in 2017.

Stratum number	N_h	N	W_h	n_h	f_h (%)	(m ²)	s_h^2
1	198	422	0.4692	28	0.1414	10272.57	111059383.60
2	78	422	0.1848	10	0.1282	23347.15	441781199.13
3	47	422	0.1114	6	0.1277	53480.35	217588913.35
4	41	422	0.0972	5	0.1220	72042.97	598687783.10
5	24	422	0.0569	3	0.1250	101778.39	85000902.09
6	17	422	0.0403	3	0.1765	116648.67	1006782408.64
7	7	422	0.0166	2	0.2857	143419.00	765673525.59
8	4	422	0.0095	2	0.5000	144819.77	2796755176.20
9	3	422	0.0071	2	0.6667	269129.69	10129222962.02
10	3	422	0.0071	2	0.6667	261057.10	1065556621.53
r (%)					7.22		
CV (%)					5.12

Introduction

Garlic (*allium sativum* L.) and onion (*Allium cepa* L.) are the important vegetable crops in Korea. The cultivation of garlic that depends on dormancy or budding is distinguished into the warm-type and cool-type, respectively. Cool-type garlic, that is the late-maturing cultivar, is cultivated in cold weather at high latitudes, and it is characterized by strong tissues and excellent storage capacity. Cool-type garlic is composed of 6 to 7 cloves and has a better appearance compared with warm-type garlic. Warm-type garlic, known as the early-maturing cultivar, was sown along the southern coast of Korea including Hapcheon, Jeonju, Namhae, Hampyung, Muan, and Shinan, and it is harder to store than cool-type garlic, however, warm-type garlic has a higher yield than that of cool-type garlic, because it is composed of more than eight cloves. In Korea, garlic and onion are mainly planted by the scattered farmers. Affected by the market situation occurred in demanders and suppliers, there is a large annual change for the two crops acreage. Therefore, timely and accurate estimates of garlic and onion acreage are critical to guiding the production of vegetable crops, adjusting agricultural planting structure and ensuring an effective supply of farm products (Chhikara et al., 1986; Quarmby, 1992; Reynolds et al., 2000; Tao et al., 2005; Song et al., 2017).

As a modern spatial information acquisition technique, satellite-based remotely sensed imagery, owing to its reality, accuracy, wide coverage and low cost, has the unique advantage of providing continuous space–time information on crop cultivation and growth at various regional scales (Mahey et al., 1993; Cihlar, 2000; Cohen and Shoshany, 2002; Ramankutty et al., 2008; Thenkabail et al., 2009; Portmann et al., 2010; You et al., 2014). Although there has been an obvious progress on crop acreage retrieving by satellite-based remotely sensed imagery, however, limited by the availability of satellite-based images and complexity of crop planting structure, there is a large challenge for accurate crop types recognition by satellite-based remotely sensed image at a large-scale regions (Song et al., 2017).

The spatial sampling technology, constructed through combining the traditional sampling methods and remotely sensed imagery, is an alternative solution for crop acreage estimation at the large-scale regions. This technology firstly retrieves the priori knowledge on sampled population (e. g. variance, mean, spatial distribution) using recent satellite-based remotely sensed images covering the whole study area with a medium spatial resolution; Secondly, the samples are selected by utilizing the traditional sampling methods; Thirdly, crop area within the sampled units is retrieved by remotely sensed imagery with a high resolution; At last, the population values of crop acreage are extrapolated and the sampling errors are estimated, based on crops area data within the sampled units. Compared with the traditional sampling survey for crop acreage summary, the spatial sampling survey has a better accuracy and timeliness. Therefore, this technology has been widely employed in crop survey and statistics business in many countries.

Different from food crops (e. g. rice, wheat, maize and so on) cultivated in a large area, garlic and onion are planted in those fragmentary and dispersive farmland plots with a small size in Korea, and there is a very common cross cropping between the two crops. It is very difficult to realize the accurate identification of garlic and onion only using satellite-based remotely sensed images. Taking Hapcheon Gun, Korea as the study area, this study' aim

is to formulate a spatial sampling scheme through combining satellite-based, UAV remotely sensed images and the stratified sampling method for improving the estimated accuracy of garlic and onion acreage. The main objectives of this study were to: (i) verifying the accuracy of garlic and onion identification by satellite-based and UAV remotely sensed images; (ii) analyzing the effects of stratification numbers on the variance of the two crops area within the strata and then optimizing the sampling survey scheme; (iii) evaluating the accuracy of population extrapolation using this optimized spatial sampling scheme for garlic and onion estimation.

Materials and Methods

The study area Hapcheon Gun is located in the south-central of Korea ($35^{\circ}23' \sim 35^{\circ}48'$ N latitude, $127^{\circ}57' \sim 128^{\circ}22'$ E longitude), and has a total land area of 983.39 km^2 . It is composed of granitic gneiss strata of Precambrian basement. 72.4% of total area is mountain. In North-west, there are mainly high mountains. In North and Center, there are mountain branch and basin. In East and South, there are the low zone. Area by elevation is same next; under 100m 22.2%, 100~300 m 48.6%, 300~500 m 18%, 500~1,000 m 10.8%, upper 1,000 m 0.3%. The climate is southern inland type and there is a big difference between heat and cold. Average annual temperature is 12.7°C . Average annual precipitation is 1,238.6 mm, 60% of them fall from June to August. Weather days are 110 days on clear days, 90 days on cloudy days, 77 days on rainy days. Garlic and onion are the most important vegetable crops in Hapcheon Gun. The total area of garlic and onion are located 743 ha and 1138 ha respectively, according to Korea statistical data in 2015, and they were mainly cultivated in central, north and east regions in Hapcheon Gun. Onions are sown in every autumn and harvested in the following April to June. For the early cultivations, the onion is harvested within 135 – 155 days, whereas late cultivations are harvested during 165 – 175 days. The cultivation of garlic that depends on dormancy or budding is distinguished as the warm- and cool-types, respectively. Cool-type garlic called the late-maturing cultivar, grows in cold weather at high latitudes, and these garlics are characterized by strong tissues and excellent storage ability. Warm type garlic, called the early-maturing cultivar, was developed along the southern coast of Korea including Hapcheon, Jeju, Namhae, Hampyung, Muan, and Shinan. Cool-type garlic is harvested from mid-June to the end of June and warm-type garlic is harvested from the end of May to early June.

The study data

(1) Fundamental geographical information

Two levels (Gun and Township) administrative boundary and in a vector format of Hapcheon Gun was acquired to define the extent of the sampling survey, for garlic and onion acreage estimation, and to help construct the spatial sampling frame. The administrative boundary of the study area is shown in Fig. 1.

(2) Satellite-based remotely sensed data

5 RapidEye satellite-based images were collected to retrieved garlic and onion in the study area in 2016 and

Fig. 1. The administrative boundary of the study area (Hapcheon-gun).

2017. RapidEye satellite was launched on August 29, 2008, and it is the first satellite constellation made up of five satellites in the world. Its sensor has a spatial resolution of 5m, and includes five bands, they are Blue (440-510 nm), Green (520-590 nm), Red(630-685 nm), Red edge (690-730 nm), Near infrared (760-850 nm), respectively. After radiation calibration, atmosphere correction and geometric precise adjustment, the RapidEye satellite-based images can be used for crop and other surface features recognition. The date of 5 images is November 9 2016, January 10, 2017, March 15, 2017, April 27, 2017, and May 22, 2017.

(3) UAV remotely sensed data

5 UAV remotely sensed images are used to retrieve garlic and crop in five sampled units. These images are taken by eBee UAV (Sensefly, Switzerland) made in Germany, and their spatial resolution is 0.08 m. The date of one image was April 28, 2017, and the date of the rest images was April 27, 2017.

(4) Cultivated land data

The cultivated land with a vector format in the study area was retrieved by Rapid Eye satellite-based images in 2016. There are two types of the cultivated land: paddy land and upland. The spatial distribution of the cultivated land in the study area is presented in Fig. 2.

Fig. 2. Spatial distribution of the cultivated land in the study area (Hapcheon-gun).

(5) Field survey data

Garlic and onion areas in five sampled units were measured by the field survey, and these field survey data was used to verify the accuracy of crop recognition by RapidEye satellite-based and UAV remotely sensed images.

Technical route The technical route consists of five steps. The first step is the preparation of basic data used to formulate the spatial sampling scheme, including basic geographical information and the spatial distribution of cultivated land and crops in the study area. The second step is the design of the spatial sampling scheme, including the formulation of the sampling unit size, stratification criteria, stratum number and samples selecting method. The third step is the retrieving of garlic and onion within all sampled units using RapidEye satellite-based and UAV remotely sensed images in 2017. The fourth step is population extrapolation of garlic and onion area using the stratified sampling scheme. The last step is error estimation and precision test of the inference result using the spatial sampling scheme for estimating the two crops area.

Garlic and onion identification by remotely sensed images The garlic and onion was retrieved and then mapped using the supervised classification method in the study area, based on the RapidEye satellite-based images on May 17, 2017 (Fig. 3). Total sample size is 750 in the supervised classification process of the remotely sensed images, twenty percent of samples were selected as Area of Interest (AOI), and the rest of samples were used to verify the

classification accuracy of the two crops. Furthermore, the priori knowledge (e. g. population variance and mean) on sampled population can be refined from the two crops map retrieved by RapidEye satellite-based images in 2016, which is the important basis for formulating the spatial sampling scheme.

The Garlic and Onion Classification Index (*GOCI*) was constructed by analyzing the DN characteristic of five typical surface objects (garlic, onion, plastic film, bare land and others) in five bands of the sensor belonging to RapidEye satellite (Fig. 4). *GOCI* is calculated using Eq. 1.

Fig. 3. Spatial distribution of garlic and onion in the study area in 2016.

Fig. 4. DN characteristic of typical surface features for five bands of RapidEye satellite sensor.

$$GOCI = (NIR - B) / (NIR + B) \quad (\text{Eq. 1})$$

where NIR is the albedo of surface objects in near infrared band of RapidEye satellite sensor; B is the albedo of surface objects in blue band of RapidEye satellite sensor.

Based on the RapidEye satellite-based images with 4 phases in 2017, the garlic and onion was retrieved by Support Vector Machine (SVM) method to obtain the truth population value and sample observation of the two crops. The spatial distribution of garlic and onion in 2017 is shown in Fig. 5.

Fig. 5. Spatial distribution of garlic and onion in the study area in 2016.

Design of the spatial sampling scheme

(1) Sampling unit

We selected 1500 m×1500 m as the sampling unit size, considering that the valid range of single flight for UAV is 1500 m×1500 m, since the UAV remotely sensed image was used to retrieve the garlic and onion in the sampled units in this study. In order to construct the sampling frame, the study area is divided by the square grids with the size of 1500 m×1500 m. Removing those grids that there is no garlic and onion planted within them, the rest of grids that crossed or was within the administrative boundary of the study area constitute all the sampling units. For the convenience of distinguishing each sampling unit, we numbered each sampling units using the identifier number in ArcGIS 10.2 software (Fig. 6).

Fig. 6. The identifier of sampling units in the sampling frame.

(2) Population stratification

Taking into account that the distribution of garlic and onion is very fragmentary and dispersive in the study area, which leads to that there is a very large variance for the two crops area within the sampling units, we used the stratified sampling method to select the samples, in order to reduce this variance within all sampling units, and thus decrease the sample size. For the population stratification design, we chose the proportion of the garlic and onion area accounting for a sampling unit area, that is crop planting intensity (*CPI*, %), as the stratification criterion, in order to improve the efficiency of the stratified sampling scheme. Considering the variance of the two crops area in sampling units is very large, we formulated 6 levels of stratum number for the sampled population, they are 5, 6, 7, 8, 9 and 10, respectively. The sample size was also calculated for the stratification design with different stratum numbers.

(3) Sample size

The total sample size is calculated using the Eq. 2 (Cochran, 1977).

$$n_0 = \frac{\sum W_h S_h^2}{V} \quad (\text{Eq. 2})$$

$$n = \frac{n_0}{1 + \frac{n_0}{N}} \quad (\text{Eq. 3})$$

$$V = \left(\frac{\gamma \bar{Y}}{t} \right)^2 \quad (\text{Eq. 4})$$

$$W_h = \frac{N_h}{N} \quad (\text{Eq. 5})$$

where n_0 is the initial sample size; n is the modified sample size. When $n_0/N > 0.05$, n_0 is modified using the Eq. 3; t is the degree of sampling probability. When confidence level is 95%, t is 1.96; N is population size; N_h is population size in h -th stratum; r is relative error limit, and 5% was selected as the relative error limit in this study; $\bar{Y}$ is population mean, that is the average garlic or onion acreage in all sampling units; S_h^2 is the variance of population units in h -th stratum.

After the total sample size was determined, and then it was allotted into each stratum using a proportional allocation. The sample size n_h in each stratum is calculated using the Eq. 6.

$$n_h = n W_h = n \frac{N_h}{N} \quad (\text{Eq. 6})$$

Fig. 7. Spatial distribution of garlic samples.

Fig. 8. Spatial distribution of onion samples.

After n_h is determined, the systematic sampling method is used to select the samples within each stratum. For this systematic sampling design, the sampling interval is k , $k = \frac{N_h}{n_h}$. The sampled units for garlic and onion area estimation were shown in Fig. 7 and Fig. 8, respectively.

(4) Sample observation

The garlic and onion acreage in the sampled units are served as the samples observation, and the two crops area is retrieved by satellite-based and UAV remotely sensed images in this study. The garlic and onion acreage in five samples (ID number is 222, 250, 263, 347 and 415) was retrieved by UAV remotely sensed data (Fig. 8), and the two crops area in the rest of samples was retrieved by RapidEye satellite-based images in 2017.

(5) Population extrapolation and error estimation

A simple estimator is used to extrapolate population values and to estimate the errors. The unbiased estimates of population mean and total are calculated by Eq. 7 and 8, respectively. The unbiased estimate of the variance of population total is estimated by Eq. 9 (Cochran, 1977).

$$\overline{y}_{st} = \sum_{h=1}^5 W_h \overline{y}_h \quad (\text{Eq. 7})$$

$$\hat{Y} = N \overline{y}_{st} \quad (\text{Eq. 8})$$

$$v(\hat{Y}) = N^2 v(\overline{y_{st}}) = \sum_{h=1}^L N_h^2 \frac{1-f_h}{n_h} S_h^2 \quad (\text{Eq. 9})$$

where $\overline{y_{st}}$ is the samples mean in stratified sampling; L is strata number; $\overline{y_h}$ is samples mean in i -th stratum; W_h is weighting in h -th stratum; S_h^2 is the variance of population units in h -th stratum; n_h is sample size in h -th stratum; $\hat{Y}$ is the estimator of population total; f_h is the sampling fraction in h -th stratum, $f_h = n_h/N_h$; $v(\overline{y_{st}})$ is unbiased estimate of samples mean variance; $v(\hat{Y})$ is the unbiased variance of population total estimator; s_h^2 is samples variance in h -th stratum.

(6) Precision evaluation

Relative error (r) and coefficient of variation of population total estimator (CV) are selected as indices to evaluate the error and stability of population extrapolation using the stratified sampling method. Relative error and CV are calculated according to Eq. 10 and 11, respectively.

$$r = \frac{|\hat{Y} - Y|}{Y} \times 100\% \quad (\text{Eq. 10})$$

$$CV(\hat{Y}) = \frac{\sqrt{v(\hat{Y})}}{\hat{Y}} \times 100\% \quad (\text{Eq. 11})$$

Where Y is the truth value of population total of the garlic and onion acreage in the study area, it was retrieved by RapidEye satellite-based remotely sensed image in 2017; $CV(\hat{Y})$ is coefficient of variation of population total estimator.

Results and Discussions

Comparison of garlic and onion classification accuracy by satellite-based and UAV remotely sensed data

Since the accuracy of garlic and onion classification using RapidEye satellite-based and UAV images has an influence on the population extrapolation of the two crops acreage in the study area, therefore, the crops classification accuracy using this two remotely sensed data should be tested. Selecting the field survey results of garlic and onion acreage in five sampled units as the reference, we compared the two crops classification precision using RapidEye satellite-based and UAV images. The result of garlic and onion classification using RapidEye satellite-based and UAV images is listed in Table 1. It can be seen that the classification error is zero, when UAV image is used to identify the garlic and onion in the five sampled units, no matter what the sample is in the plain or highland. It indicates UAV image can completely be used to retrieve crops area within sampled units, when the spatial sampling survey is employed to estimate the garlic and onion acreage. Compared with the UAV image, there is a certain

error, when RapidEye satellite-based images is used to retrieve the two crops area in the sampled units, especially, the garlic classification error is the larger than that of onion. The reason is that the omission errors of garlic classification are the larger than that of onion, due to that garlic has a similar spectral characteristic with other crops, such as wheat. Furthermore, the garlic classification error within two sampled units, which their ID number is 263 and 415, is up to 157.89% and 164.09% respectively. The reason is that the two sampled units are both located in highland (Fig. 9), and the cultivated land plots within the two units are very irregular and fragmentary. Otherwise, when the sampled units are located in the plain, such as the units that their ID number is 222, 250 and 347, the error of garlic classification using RapidEye satellite-based images is relatively lower, and all less than 10%. It indicates RapidEye satellite-based image can be used to retrieve garlic acreage of the sampled units in the plain region.

Table 1. Results of garlic and onion classification by RapidEye satellite-based and survey by UAV remotely sensed data.

Sample ID number	Survey by visual reading and UAV data		Survey by RapidEye data		Classification error using RapidEye data (%)	
	Garlic area (m ²)	Onion area (m ²)	Garlic area (m ²)	Onion area (m ²)	Garlic	Onion
222	359,214	566,215	334,280	748,023	6.94	32.11
250	166,852	182,523	182,215	183,304	9.21	0.43
263	28,919	40,442	74,580	38,378	157.89	5.10
347	366,363	232,376	340,296	233,251	7.12	0.38
415	39,844	92,186	105,226	105,122	164.09	14.03

Compared with the garlic, the error of onion classification using RapidEye satellite-based image is the lower. The maximum error of onion classification occurs in the sampled unit which its ID number is 222, and the two sampled units which their ID number is 263 and 415 have the less classification errors. For the sampled unit that ID number is 222, it is the reason for the largest classification error that there is a common cross cropping between onion and other crops (e. g. barely) with a similar growing period, which leads to a large commision error. However, for the two sampled units which their ID number is 263 and 415, it is the reason for the larger errors that the cultivated land plots in these units are very irregular and fragmentary.

Influences of population stratification numbers on sample size The calculated sample size for six levels of stratum number is listed in Table 2, in order to analyze the influence of stratum number on the required sample size for meeting the formulated accuracy of population extrapolation. It can be seen that the required sample size, which can be fit for the designed precision (95%) of population inference, decreases with the number of population stratification increasing, moreover, its reduction is very significant; meanwhile, the variance of the two crops area within each stratum also decreases with the stratum number increasing. It indicates that the variance of the two crops area with each stratum can be significantly decreased, when the proportion of garlic and onion acreage accounting for one sampling unit area was selected as the stratification criterion.

Table 2. Results of the calculated sample size at 6 levels of stratum number.

Stratum number	N	n	$f(\%)$	Variance within all the strata	Population mean
5	422	346	81.99	581645443.61	53806.23
6	422	242	57.35	309484505.86	53806.78
7	422	171	40.52	225594090.28	53806.12
8	422	93	22.04	214765934.96	53806.45
9	422	75	17.77	171967843.32	53806.45
10	422	63	14.93	139588442.75	53806.59

Note : Population size should be 423, however, there is a sampling unit which ID number is 222 in the sampling frame, and the garlic and onion area within this sampling units is very large. In order to decrease the variance within the strata, this sampling unit was chosen as the constant units, which means that this unit will not be drawn in the sampling survey for garlic and onion area estimation. Therefore, population size ultimately became 422.

Fig. 9. Crop planting boundary delineated by UAV remotely sensed image in the sampled unit. The large red hollow box denotes the boundary of the sampled unit; red polygons denote crops planting boundaries in the sampled unit; background is from RapidEye satellite image in 2017.

Fig. 10 shows the change of the required sample size and variance within each stratum with the stratum number increasing. It may be observed that the variance of garlic and onion acreage in each stratum decreases with the stratum number increasing, consequently, the required sample size is also reduced due to the reduction of the variance of the two crops area within all strata. When the stratum number is 10, accordingly, the required sample size is the minimum. Table 3 lists the population parameters and the calculated sample size with 10 strata in the sampling frame. It can be seen that the calculated sample size only is two for the 7th, 8th, 9th, and 10th stratum, which means that it has reached the minimum value of sample size in each stratum, when the population stratification

number is 10. Comprehensively considering population extrapolating accuracy, sampling survey cost and rationality, we select 10 strata as the optimum stratification number of the sampled population.

Fig. 10. Changes of sample size and variance with the stratum numbers.

Table 3. Population parameters and the calculated sample size with 10 strata in the sampling frame.

Stratum Number	N_h	W_h	n_h	$\bar{Y}_h$	S_h^2
1	198	0.47	28	8540.03	39595626.52
2	78	0.18	10	33661.54	40350124.88
3	47	0.11	6	54219.00	43749850.00
4	41	0.10	5	79096.95	44892912.35
5	24	0.06	3	119833.33	284724764.49
6	17	0.04	3	187783.82	370803042.28
7	7	0.02	2	256928.57	1280992380.95
8	4	0.01	2	367018.75	1587528489.58
9	3	0.01	2	484083.33	192778958.33
10	3	0.01	2	603675.00	4996594375.00
Sum	422	1.00	63	53806.59	139588442.75

Note : $\bar{Y}_h$ is the average garlic and onion acreage within sampling units in the h-th stratum ; S_h^2 is the variance of garlic and onion acreage within sampling units in the h-th stratum.

Population inference and error estimation on garlic and onion acreage in 2017 Selecting the stratified sampling method, that the stratification criterion is the proportion of crops area accounting for one sampling unit area and the stratum number is 10, to draw the samples and extrapolate population values. Taking the garlic and onion acreage retrieved by RapidEye satellite-based image in all sampled units and the study area in 2017 as sample observations and truth population total. Using UAV images and field survey data in five sampled units as the validation data for verifying the accuracy of the two crops classification by RapidEye satellite-based image, we conducted an extrapolation for total garlic and onion acreage in the study area in 2017, and then error estimation and stability evaluation for this extrapolated results. The population extrapolation and error estimation results of garlic and onion acreage in 2017 using the spatial stratified sampling scheme were list in Table 3 and Table 4,

respectively. It can be seen that the relative error and *CV* of population extrapolation are both less than 10%, when the stratified sampling scheme combining satellite-based and UAV remotely sensed images was used to estimate garlic and onion area in the study area. It indicates the spatial stratified sampling scheme combining satellite-based and UAV remotely sensed images has a high accuracy and stability for the two crops acreage estimation. Furthermore, it can also be seen that the relative error of garlic population extrapolation is very similar with that of onion. It indicates that a set of samples just is enough to extrapolate the garlic and onion acreage, when the proportion of the total area of garlic and onion accounting for one sampling unit area was selected as the stratified criterion.

Table 4. Results of population extrapolation and error estimation for garlic acreage in the study area in 2017.

Stratum number	N_h	N	W_h	n_h	f_h (%)	(m ²)	s_h^2
1	198	422	0.4692	28	0.1414	10272.57	111059383.60
2	78	422	0.1848	10	0.1282	23347.15	441781199.13
3	47	422	0.1114	6	0.1277	53480.35	217588913.35
4	41	422	0.0972	5	0.1220	72042.97	598687783.10
5	24	422	0.0569	3	0.1250	101778.39	85000902.09
6	17	422	0.0403	3	0.1765	116648.67	1006782408.64
7	7	422	0.0166	2	0.2857	143419.00	765673525.59
8	4	422	0.0095	2	0.5000	144819.77	2796755176.20
9	3	422	0.0071	2	0.6667	269129.69	10129222962.02
10	3	422	0.0071	2	0.6667	261057.10	1065556621.53
r (%)					7.22		
CV (%)					5.12		

Table 5. Results of population extrapolation and error estimation for onion acreage in the study area in 2017.

Stratum number	N_h	N	W_h	n_h	f_h (%)	(m ²)	s_h^2
1	198	422	0.4692	28	0.1414	3813.57	30599569.76
2	78	422	0.1848	10	0.1282	9657.25	93487450.87
3	47	422	0.1114	6	0.1277	35890.03	368213152.65
4	41	422	0.0972	5	0.1220	36619.43	360378893.38
5	24	422	0.0569	3	0.1250	73382.43	791053868.64
6	17	422	0.0403	3	0.1765	78369.40	1479645138.29
7	7	422	0.0166	2	0.2857	169237.54	5758705883.06
8	4	422	0.0095	2	0.5000	262786.02	12634814964.08
9	3	422	0.0071	2	0.6667	197289.46	2586428031.66
10	3	422	0.0071	2	0.6667	280473.33	12357622326.18
r (%)					7.48		
CV (%)					9.34		

Conclusions

Taking Hapcheon Gun, Korea as the study area, we explored a spatial stratified sampling scheme through a combination of RapidEye satellite-based and UAV remotely sensed data, and then employed this sampling scheme to select sampled units, extrapolate garlic and onion acreage and estimate the sampling error, in order to improve the accuracy of the vegetable crops acreage monitoring. The experimental results are as follows:

- (1) The error is found in the two crops classification using RapidEye satellite-based images, especially, garlic classification error is the larger than that of onion. Compared with the plain regions, there is a larger error of the two crops classification using RapidEye satellite-based data in the high land regions, due to that the cultivated land plots are irregular and fragmentary in them.
- (2) The variance of garlic and onion area within each stratum can be significantly decreased, when the proportion of the two crops acreage accounting for one sampling unit area. The required sample size for meeting the designed extrapolation accuracy decreases with the stratification number of the sampled population increasing. Comprehensively considering population extrapolating accuracy, sampling survey cost and rationality, 10 strata is the optimum stratification number.
- (3) The relative error and *CV* of population extrapolation are both less than 10%, when the stratified sampling scheme combining satellite-based and UAV remotely sensed images was used to estimate garlic and onion area in the study area, which indicates the spatial stratified sampling scheme proposed in this study has a high accuracy and stability for the two crops acreage estimation.

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