Assessment of cropland area on sloping land in DPRK

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Abstract. Following the famines of the mid 1990s, the government of the Democratic People’s Republic of Korea (DPRK) authorized cultivation on sloping land before deciding, in the years 2000, to limit this practice on slopes above 15 degrees in order to reduce erosion. There are still many cultivated fields on slopes and their total estimated area ranges from 300,000 ha to more than 2 million ha. This study aims at assessing cropland areas on slopes above 10 and 15 degrees by using high to very high resolution remote sensing satellite imagery. For this purpose, a grid of points was superimposed over the DPRK territory and stratified according to slope, as derived from two DEMs, the 30 m ASTER GDEM V2 and the 3 arc second (90 m) SRTM Dem V4. A sample of about 2100 points was drawn using an optimal allocation sampling plan, based on a preliminary assessment of the variance of the estimated cropland percentage per class of slope. These 2100 points were interpreted into cropland, no cropland and doubt using mostly Google Earth imagery acquired after 2004. For slopes above 10 degrees, the area cropped was estimated to be around 1,000,000 ha (5.6% CV) and 742,000 ha (8.1% CV) according to the ASTER and SRTM DEM respectively. Above 15 degrees, the estimated cropland area ranges from 360,000 ha (9.7% CV) with SRTM to 540,000 ha (6.6% CV) with ASTER. To decide between these two estimations, a validation of the two DEMs should be carried out on a region with similar relief. Alternatively, a higher accuracy DEM such as the one to be derived from the TanDEM-X mission in 2014 should provide more accurate estimates of the cropland area on sloping land.

1. Introduction

Of the 122,000 km² of DPRK land area, about 17% (2 million hectares) are dedicated to crops, namely 1.4 million hectares to cereals, 0.3 million ha to vegetables and the balance to fruit orchards and industrial crops such mulberry, cotton, tobacco and ginseng [1].

During the famines of the mid and late 90s, the population (mainly urban women and elder people) looked for additional land to cultivate in order to complement the insufficient rations distributed by the Public Distribution System; as a result slopes above 15 degrees were allowed to be deforested and put into cultivation (see typical landscape in Fig 1); however, after some years, erosion and increased flooding events led the government to limit cultivation (in particular of maize), promote planting of slope-friendly crops (e.g. sweet potato) along the contour lines and develop reforestation and agro-forestry (combination of trees and crops) on these slopes.

According to the DPRK government, 300,000 ha of cereals are grown on sloping land whereas other sources (NGOs) estimate this area to be up to 2.5 million hectares (i.e. more than the total area cropped by state farms). Despite the low yields expected on such slopes (0.5 t/ha is assumed due to low soil fertility and poor crop husbandry versus 3 to 5 t/ha for cereals in cooperative farms), an
independent estimate of this area is needed by the DPRK government as well as the international community of donors in order to compute the food balance sheet of the country.

The aim of this short study is to assess the cropland areas on slopes above two thresholds: the official one of 15° (i.e. 27%), and 10° (i.e. 18%) as erosion is likely to take place on such slopes. Since field survey is not feasible, this assessment should be based on remote sensing images acquired after the main deforestation period.

2. Method and data
The method is based on the photointerpretation of a sample of points using high resolution (typically Ground Sampling Distance (GSD) of 5 to 30m) or preferably very high resolution (GSD of 1m or lower) remote sensing imagery. The interest of using remote sensing imagery is twofold:
(1) it allows “stratifying” the territory, i.e. identifying the respective shares of (general) classes of land cover types in an efficient way; such a stratification based on a grid of points interpreted on (1m or better) ortho-photo imagery is used for the European Land Use/Cover Area-frame Statistical (LUCAS) survey which is conducted roughly every three years in Europe since 2001 [2];

(2) it replaces ground visits when these are not possible provided that the feature to be observed can be interpreted on remote sensing imagery with a high degree of confidence.

In our case, the classes requested are simply “cropland” and “no cropland”. Moreover we did not need current year or very recent imagery since the main deforestation took place at the end of the 90s.

The sampling design detailed below was based on a two-phase scheme: the first phase consisted in a systematic sampling based on a regular grid of points (as in LUCAS); this sample of points was stratified according to slope; then a subsample of points inside the slope classes of interest was selected and photo-interpreted on remote sensing imagery.

2.1. Imagery used
We used Google Earth imagery as it was considered to be the best imagery (from a GSD and acquisition date perspective) available for the whole country at the time of the study. The type and acquisition date of the images were assessed using 136 points taken from a 30 km grid. All the 136 images analysed were acquired after 2000 i.e. after the main deforestation period, which met our requirements; more precisely 99% and 94% of the images were acquired after 2004 and 2006 respectively. As for resolution, nearly 80% of the images had a 1m or lower GSD suitable for photointerpretation (108 out of 136 were Geoeye or Digital Globe images) while the remaining 20% were Spot images with a GSD of 10 or 20m. In case of doubtful interpretation due to poor image quality (low resolution or snow coverage), Bing map VHR imagery was used wherever available; otherwise the point was considered as doubtful.

2.2. Map of slopes
The slope for each (sampled) point was derived from the Global Digital Elevation Model Version 2 (GDEM V2) derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor onboard the NASA Terra satellite (see Fig. 2). This DEM, released in October 2011, was generated using about 1.5 million stereo-pair near-infrared images collected along track at a 15m resolution by the ASTER instrument. We chose this DEM for its 30 m posting, i.e. the finest resolution available among public DEMs over DPRK, for two reasons: this resolution is consistent with the field size on sloping land (see Fig. 5) and according to [3] the accuracy of slope decreases with lower resolution, especially in areas of steep slopes (i.e. high relative relief); moreover slopes tend to decrease with increasing resolution [3, 4], i.e. a coarser DEM may underestimate steep slopes. The elevation data was obtained in GeoTIFF format and in tiles of 1 by 1 degree, which were reprojected to UTM 52. The slope image was derived using the third order finite difference algorithm of Horn [5] implemented in ArcGIS 10.

2.3. Preliminary assessment of cropland percentage per class of slope
In order to optimize the sampling plan, we needed an estimate of the percentage of cropland per class of slope as the variance of estimate is directly linked to the probability of “cropland” (we assume that the photo interpretation of a point into cropland / non cropland behaves according to Bernoulli’s law). A preliminary assessment was therefore made by photo-interpreting 200 points in each of the following three classes of slopes: 0 – 10 degrees, 10 – 30 degrees and 30 – 90 degrees. These 600 points were obtained by superimposing a 6 km grid on the territory of DPRK and randomly drawing 200 points per class of slope (Table 1).
The classes assigned by the interpreter were the following: (1) cropland (mainly arable land and pastures as permanent woody crops may be difficult to separate from natural woody vegetation), (2) non agriculture, (3) thematic doubt (when the interpreter cannot determine whether the point is cropland or not) and (4) geometric doubt (when the point falls at the border between cropland and non-agricultural land). Points falling in these last two classes were later reassigned to the first two classes by assuming an equal probability (50%) of belonging to cropland or non-agricultural land.

**Table 1.** Preliminary stratification of DPRK in three classes of slope.

| Class of slope | Number of points | Area (km²) | Percentage of country area |
|----------------|------------------|------------|---------------------------|
| 0 – 10°        | 1115             | 39,104     | 31.9%                     |
| 10 – 30°       | 1914             | 68,992     | 56.3%                     |
| 30 – 90°       | 390              | 14,430     | 11.8%                     |
| Total          | 3419             | 122,526    | 100.0%                    |

**Figure 2.** ASTER DEM with the 6 km grid of points and their associated slope.
The results of the photo-interpretation of these 600 points are given in Table 2. Thematic doubt was assigned to 6 points (3%) in each of the first two strata and 5 points (2.5%) in the third one (30–90°) while no point was considered as geometric doubt. The highest standard error of estimate is found for the 0–10° stratum where the probability to have cropland is close to 50%. This probability falls to 16% in the 10–30° stratum and to less than 4% in the 30–90° stratum. The five points found to be cropland in the 30–90° stratum have a slope very close to 30° and were located close to villages.

Table 2. Photointerpretation results of the preliminary assessment (estimated cropland area in % of stratum size and ha, standard errors of estimate in % of stratum size and ha)

| Class of slope | Cropland area and standard error (%) | Cropland area and standard error (ha) |
|----------------|-------------------------------------|--------------------------------------|
| 0 – 10°        | 49.0% (3.5%)                        | 1,916,100 (138,200)                  |
| 10 – 30°       | 16.0% (2.6%)                        | 1,103,900 (178,000)                  |
| 30 – 90°       | 3.8% (1.3%)                         | 54,100 (19,400)                      |

According to this preliminary sample and on the basis of a country area of 122,526 km², we estimate at 1.9M ha the cropland area in the 0–10° class of slopes (Table 2). These 1.9M ha compare favorably to the 2M ha considered as cultivated by cooperative farms [1], which break down into 1.4M ha suitable for cereals, 0.3M ha of vegetable crops, 0.16M ha of fruit orchards and about 0.2M ha of industrial crops (mulberry, cotton, tobacco and ginseng). For the cropland area on slopes above 10°, our first estimate amounts to 1.1M ha, with a standard error around 180,000 ha.

2.4. Sampling design
The final survey was based on an optimal allocation sampling plan in order to achieve the highest precision for a given number of sample elements: the number of sample points per class of slope was set to be proportional to the product of the variance (function of the cropland proportion) by the stratum size. Four classes of slope (strata) were considered: 10 to 20°, 20 to 30°, 30 to 40°, and above 40°. The 0 to 10° stratum was not sampled as our focus is on cropland areas on slopes above 10°.

Table 3. Characteristics of the various strata and number of sample points per class (and sampling rates) according to the three possible sampling schemes

| Stratum  | Stratum size | Cropland area (%) | Variance | Variance x stratum size | Plan 1 | Plan 2 | Plan 3 | Plan1* |
|----------|--------------|-------------------|----------|-------------------------|--------|--------|--------|--------|
| 10 – 20° | 1055         | 17%               | 0.14     | 151.32                  | 564    | 1055   | 1055   | 1193   |
| 20 – 30° | 859          | 14%               | 0.12     | 102.95                  | 384    | 718    | 859    | 812    |
| 30 – 40° | 344          | 4%                | 0.04     | 13.88                   | 52     | 97     | 178    | 109    |
| Above 40°| 46           | 0%                | 0.0      | 0.0                     | 0      | 0      | 22     | 0      |
| Total    | 2304         |                   |          |                         | 1000   | 1870   | 2114   | 2114   |

Table 3 shows the estimated variances per stratum (derived from the 400 points with slope above 10 degrees of the preliminary assessment) and the alternative sampling plans:
• (1) in plan 1, the optimal allocation is computed for a total number of sample elements of 1000 points;
• (2) in plan 2, all the points falling in the class 10 to 20° are selected to increase the precision for this class. We took this decision considering that less than two days would be needed to photo-interpret the 500 additional points (on average 400 points are interpreted in a day) while for the two other classes of slope, the numbers of sample points are adjusted to keep the sampling rates proportional to the [variance x stratum size] criterion;
• (3) in the final sampling plan (plan 3), all the points falling in the class 20 to 30° (i.e. 141 additional points) are also included in the sample as well as the 200 points already photo-interpreted in classes above 30°, which leads to a total sample of 2114 points. The comparison of plan 3 with respect to the optimal allocation for 2114 points (see plan 1*) shows sampling rates slightly higher than the optimal allocation ones, especially for strata above 30°, for a total workload that is still acceptable (5 days of interpretation). The final sample includes about 2100 points, of which 400 were already photo-interpreted in the preliminary assessment.

3. Results and discussion
The interpretation of all 2114 sample points is summarized inTable 4 and examples are given in Figures 3 to 6. Since the area cultivated on slopes above 15° is of interest, the 10 to 20° stratum was subdivided into two strata (10 to 15° and 15 to 20°).
Table 5 provides the cropland area per class of slope (after re-assignation of 50% of the doubtful points to the cropland stratum) and the associated standard error of estimate. For slopes above 10 and 15° according to the Aster DEM the cropland area is estimated to be around 1,000,000 ha and 540,000 ha respectively, with standard errors of estimates of 56,000 (CV of 5.6%) and 44,000 ha (CV of 8.1%) respectively.

| stratum     | Cropland | Non cropland | Thematic doubt | Geometric doubt | Total |
|-------------|----------|--------------|----------------|-----------------|-------|
| 10 – 20°    | 184      | 844          | 11             | 16              | 1055  |
| 20 – 30°    | 66       | 777          | 10             | 6               | 859   |
| 30 – 40°    | 4        | 171          | 2              | 1               | 178   |
| Above 40°   | 0        | 22           | 0              | 0               | 22    |
| 10 – 15°    | 128      | 402          | 6              | 7               | 543   |
| 15 – 20°    | 56       | 442          | 5              | 9               | 512   |
Figure 3. Example of thematic doubt on high resolution image (Landsat TM, scale 1:4000) with the SRTM grid displayed in red.

Figure 4. Example of thematic doubt on VHR imagery (scale 1:1000) with the SRTM grid in red.

Figure 5. Example of geometric doubt on Google Earth, scale 1:1000 with the Aster and SRTM grids in light blue and red respectively.

Figure 6. The same point represented in 3D by Google Earth. The field size and both the 30m Aster grid (in blue) and the ~90m SRTM grid (in red).
Table 5. Final ASTER results: cropland area per stratum (class of slope) in percentage of the stratum size and in ha with standard error of estimate (ha) and coefficient of variation. The estimations for strata 10-90° and 15-90° are based on the figures for strata 10-15° and 15-20° (and not from stratum 10-20°).

| Stratum | Stratum size (ha) | Cropland area (%) | Cropland area (ha) | Standard error (ha) | CV   |
|---------|------------------|-------------------|-------------------|-------------------|------|
| 10 – 20° | 3,802,482        | 18.7              | 711,839           | 45,687            | 6.4% |
| 20 – 30° | 3,096,712        | 8.6               | 266,771           | 29,663            | 11.1%|
| 30 – 40° | 1,255,701        | 3.1               | 38,800            | 16,333            | 42.1%|
| Above 40° | 187,281         | 0.0               | 0                 |                   |      |
| 10 – 15° | 1,893,260        | 24.8              | 468,957           | 35,105            | 7.5% |
| 15 – 20° | 1,909,222        | 12.3              | 234,924           | 27,744            | 11.8%|
| 10 – 90° | 8,342,176        | 12.1              | 1,009,452         | 56,114            | 5.6% |
| 15 – 90° | 6,448,916        | 8.4               | 540,495           | 43,776            | 8.1% |

The main sources of uncertainty are the photo-interpretation doubts and mistakes, the sampling error (which is linked to the number of interpreted points) and the error in the slope estimation. The number of photo-interpretation doubts was relatively low (less than 3% doubtful points in total with a maximum rate of 2.8% for the 15 to 20° stratum) and their impact can be assessed by assigning all doubtful points to one class or the other. Assigning all doubtful points to cropland or non-cropland would change the estimates by +/- 88,000 ha and +/- 65,500 ha for the cropland area above 10 and 15° respectively.

As for the sampling error, increasing the number of photo-interpreted points reduces the standard error of estimate (for instance interpreting 5500 points instead of 2100 would result in CV of 3.4% and 5.0% for slopes above 10 and 15° respectively) but should not change substantially the estimated cropland area (the estimated cropland area on slopes above 10° went from 1.1 to 1.0 million ha between tables 2 and 5).

Slope estimation is actually the main source of error. This estimation is affected by the DEM accuracy, the algorithm used for calculating the slope, DEM spacing and, to a lesser extent, DEM data precision (see e.g. [6], [7], [8]). According to simulations of synthetic terrain surfaces, the Horn’s algorithm is one of the most accurate methods for computing slope [6]. As for the impact of the DEM characteristics (RMSE and spacing) on the calculation of the slope, [7] and [8] point that the error on the slope increases proportionally to the DEM RMSE and decreases with increasing DEM spacing. For DPRK, the alternative to ASTER GDEM is SRTM 3” (~ 90m x 70m) which is derived by thinning (i.e. subsampling) of SRTM 1” (~ 30m). According to assessments made over the USA using GPS points, SRTM 1” has an RMSE which is half the RMSE of ASTER GDEM V2 (4 m against 8.7 m) [9]. Moreover the ASTER DEM error varies with the land cover height, the RMSE with respect to the bare Earth surface being significantly higher on forested areas (this is also the case for SRTM, probably to a lower extent as the SRTM campaign was made in February to minimize the effect of tree leaves in the northern hemisphere); according to our field observations, a large part of the fields on sloping land are surrounded by low height vegetation cover (e.g. scrubs or young trees), which should lower the land cover effect. To conclude, the quality of the DEM seems to be the main factor affecting the slope estimation and, a priori, SRTM, with its presumed lower RMSE (estimated on SRTM 1” while we are using SRTM 3”) and higher spacing, is likely to result in more accurate slopes, although it “underestimates slope in steep topography” according to [4].
In order to assess the impact of DEM on the cropland area, we computed the slope from version 4 of the SRTM 3" DEM using the Horn algorithm. As expected, SRTM slopes are on average smaller than Aster slopes (see the distributions of ASTER and SRTM slopes on Fig. 6 as well the regression line between SRTM and ASTER slopes on Fig. 7); this is also shown by the respective areas of the 10-90° and 15-90° strata: 8.3 and 6.4M ha respectively for ASTER against 7.5 and 5.2M ha for SRTM (table 7). Moreover the agreement between the two types of slopes appears to be moderate (R² of 0.40 on the 3399 grid points having both slopes - Fig. 7). Of the 2114 interpreted points, all with an ASTER slope above 10°, 473 had an SRTM slope below 10°. Conversely, 388 points not included in the ASTER sample (where all points with a slope between 10 and 30° were photo-interpreted) had an SRTM slope above 10° and had to be interpreted. Actually, of these 388 points, 362 points needed to be interpreted to reach a sampling rate of 100% for the 10-20° and 20-30° SRTM classes of slope; by interpreting 26 additional grid points, we could also reach a 100% sampling rate for the two strata above 30°.

Table 6 shows the results of this interpretation and Table 7 the cropland area estimates. According to the SRTM DEM, the cropland area on slopes above 10 and 15° is estimated to be around 742,000 ha and 360,000 ha respectively, with standard errors of estimates of 49,000 (CV of 6.6%) and 35,000 ha (CV of 9.7%) respectively.

![Figure 6. Distributions of Aster and SRTM slopes over the 6km grid points](image)

![Figure 7. Relationship between the Aster Dem slope and the SRTM slope over the 6 km grid points](image)

| Table 6. Interpretation of the final sample based on SRTM slope (2029 points in total) |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| stratum            | Cropland | Non cropland | Thematic doubt | Geometric doubt | Total          |
|---------------------|-----------|--------------|----------------|-----------------|----------------|
| 10 – 20°            | 145       | 1033         | 18              | 11              | 1207           |
| 20 – 30°            | 28        | 660          | 5               | 4               | 697            |
| 30 – 40°            | 9         | 108          | 0               | 1               | 118            |
| Above 40°           | 0         | 7            | 0               | 0               | 7              |
| 10 – 15°            | 95        | 489          | 11              | 5               | 600            |
| 15 – 20°            | 50        | 544          | 7               | 6               | 607            |
Table 7. Final SRTM results: cropland area per stratum (class of slope) in percentage of the stratum size and ha with standard error of estimate (ha) and coefficient of variation

| Stratum | Stratum size (ha) | Cropland area (%) | Cropland area (ha) | Standard error (ha) | CV |
|---------|------------------|-------------------|--------------------|---------------------|----|
| 10 – 20° | 4,415,157        | 13.2              | 583,445            | 43,055              | 7.4% |
| 20 – 30° | 2,578,021        | 4.7               | 120,209            | 20,603              | 17.1% |
| 30 – 40° | 447,567          | 8.1               | 36,033             | 11,258              | 31.2% |
| Above 40° | 17,757         | 0.0               | 0                  |                     |     |
| 10 – 15° | 2,222,255        | 17.2              | 381,487            | 34,239              | 9.0% |
| 15 – 20° | 2,192,902        | 9.3               | 204,117            | 25,882              | 12.7% |
| 10 – 90° | 7,458,502        | 9.9               | 741,846            | 48,923              | 6.6% |
| 15 – 90° | 5,236,247        | 6.9               | 360,359            | 34,944              | 9.7% |

Conclusion

This study over DPRK aimed at estimating the country cropland area on slopes above 10 and 15° by photo-interpretation of a sample of points on very high resolution remote sensing imagery.

Two types of DEM, namely the 30m ASTER DGEM V2 and the 3" (~90m) SRTM DEM V4 respectively, were used to derive the slope for each of the 3400 points of a 6 km grid overlaid over the country. These points were stratified as a function of their class of slope and sampled according to a modified optimal allocation sampling plan in which the number of sampled points per stratum was set to be (roughly) proportional to the stratum size multiplied by the variance of cropland estimation (inferred from the photo-interpretation of a preliminary sample of points). The selected 2100 points with a slope over 10° were then photo-interpreted into cropland, non cropland and doubt (later reassigned to cropland with a 50% probability) using mostly Google Earth imagery.

The cropland area on slopes above 10° was estimated to be of 1,000,000 ha and 742,000 ha using ASTER and SRTM DEMs respectively, with standard errors of 56,000 and 49,000 ha respectively. On slopes above 15° the cropland area was estimated at 540,000 ha and 360,000 ha for ASTER and SRTM DEMs respectively, with standard errors of 44,000 and 35,000 ha respectively. The real figure is therefore likely between 290,000 and 630,000 ha, i.e. far below the 2.5M ha assessed by NGOs. The visual impact of fields on steep slopes as well as the difficulty in visually estimating slope may have led to this over-estimation. While the ASTER DEM could appear as the most suitable DEM because its 30 m posting is closer to the fields size, the 90 m but more accurate SRTM DEM resulted in lower slopes but also more accurate ones according to our literature review. Accordingly, the most plausible estimation of the cropland area on slopes above 15° would be 360,000 ha, a figure which is close to the official figure of the DPRK government. A more accurate estimation of the cropland area on sloping land could be obtained with a higher accuracy DEM such as the one of the TanDEM-X mission (12 m posting, relative vertical accuracy better than 2m) which should be released in 2014. Alternatively, a validation study of both the 3" SRTM and ASTER DEMs could be carried out on areas with similar relief, using a high accuracy DEM in order to determine the most appropriate global DEM for our purpose.
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