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A simple method for mapping woody plant cover in agricultural fields using airborne lidar

Short communication

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Abstract. Information about the status of agricultural land is of strategic interest in every country. In Estonia, different and even contradicting estimates of area of actively used as agricultural land exist. To solve this problem, airborne laser scanning (ALS) data can be used to map the woody plant cover (values range from 0 to 1 corresponding to the no cover and full tree canopy cover) in agricultural land and to provide digital maps for further analysis. Canopy cover was estimated from ALS data by setting reference height to 2 m from ground. Validation dataset was created from ortophotos on 442 rectangular 100 m^2 elementary sampling units. The relationship was linear and determination coefficient was high (R^2 = 0.795) and the model fitting residual standard error was 0.116 indicating good applicability of ALS for woody plant cover mapping. The method can be easily automated, does not require additional fieldwork and can be applied in all places where ALS data are available.

Key words: airborne laser scanning, abandoned agricultural land, afforestation.

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Introduction

Land use in Estonia has undergone significant changes during the last 25 years after regaining independence when the Soviet Union collapsed. The end of collective farming, changes in export markets and land restitution to private owners were reasons why according to expert estimates (Vipper *et al*., 1996) about one third of the agricultural land was abandoned at the middle of 1990s according. Peterson and Aunap (1998) analysed multitemporal Landsat MSS images for period 1990–1993 and found that 32% of arable land was abandoned compared to the baseline year, 1990. General estimates about land use in Estonia are produced as a co-product of the National Forest Inventory (NFI) since 1999 (Adermann, 2010). The area of agricultural land has on average been about 1350 thousand ha showing no significant trends of increase or decrease (Figure 1, according to data from Kohava, 2000, 2001; Viilup, 2002, Adermann, 2003, 2005, 2006, 2009, 2012; Pärt, 2005; Pärt et al., 2008, 2009). A rather interesting trend according to the NFI results is the increase of arable land area and the decrease of natural grasslands during 1999–2010 (Figure 1) reaching the areas comparable to the figures presented by Mander & Palang (1994) for the period 1987–1992. Raudla (2010) summarises from official statistics that the

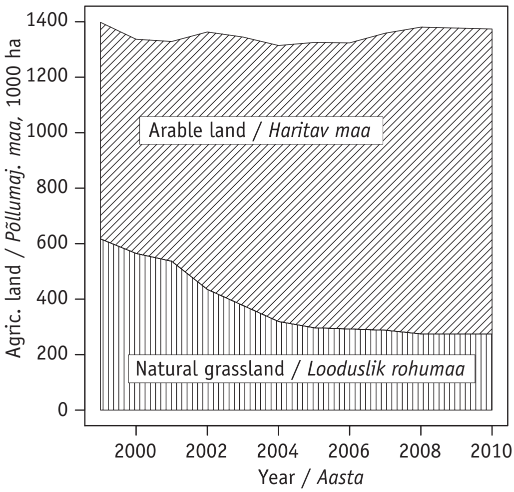

Figure 1. Agricultural land area in Estonia during 1999–2010 according to Estonian NFI.
Joonis 1. Põllumajandusliku maa pindala ajavahemikus 1999–2000 Eestis statistilise metsainventuuri andmetel.

area of field crops in 2009 was 566.6 thousand ha, which is about half of the arable land area (1105.6 thousand ha) reported by NFI (Adermann, 2009). A conclusion could be that about half of the arable land was used as grassland or was left temporarily fallow in 2009. However, both estimations are influenced by the possible differences in the land use category definition and by the differences in the data collection methods. According to the GIS database of the Estonian Agricultural Registers and Information Board (PRIA) from 2003 onwards 1232 thousand ha of actively used agricultural land were declared for European Union common agricultural policy. However, in 2009, 2010 and 2011 applications for subsidies were submitted only for 1127, 973 and 953 thousand ha of land. The status of non-applied agricultural land is unknown and this land has probably been abandoned.

The most common process in abandoned former agricultural land in this Baltic region is natural succession. Peterson *et al.* (2004) show that forests can be mapped using medium spatial resolution satellite images from late winter when snow cover is still persisting but sun is already high enough during the image acquisition. Advantages of the proposed method include low costs and the option to obtain estimates rapidly over large territories. The most problematic practical issues of this method are a lack of cloud free images and the inability to detect tree cover until trees cast a sufficient amount of shadows over snow.

An alternative tool that provides information on plant canopy is airborne lidar (Næsset, 1997). One variable that characterises plant canopy is canopy cover *K* defined as the ratio of canopy vertical projection area to observed area (Jennings *et al.*, 1999; Korhonen *et al.*, 2006). An estimate of canopy cover can be obtained using a vertical sighting tubes (Cajanus tubes, see Rautiainen *et al.*, 2005) and counting canopy hits. Airborne laser scanning data can be used in similar manner (Morsdorf *et al.*, 2006; Lang, 2010; Korhonen *et al.*, 2011).

In this short communication, a simple method is presented for mapping woody plant cover in agricultural fields. The method is based on the estimation of canopy cover at a reference height from ground level, which is not achievable for regular field crops but by trees. The outcome of the proposed procedure is a sufficiently generalized vector map that can be further used in spatial queries. Possible shortcomings and preferences of the method are discussed.

Material and Methods

ALS data acquired by Estonian Land Board with a Leica ALS50-II device in summer 2010 over Järvselja Forest Experimental and Training Forest District, South East Estonia, were used. Agricultural fields were mostly present in the southern part of the territory. The lidar's footprint size at ground level was 0.54 m and average pulse return density was 0.34-0.60 returns m^{-2}. The automatic gain control AGC of the scanner (Vain *et al*., 2009) was set on during measurements. The Leica ALS560-II device registers up to four returns per emitted pulse.

The lidar data were then processed using FUSION toolset (McGaughey, 2012). The ALS data preparation included extraction of near-to-ground returns, the establishment of ground surface digital elevation model (DEM) and the calculation the pulse return heights from the DEM. To extract the canopy cover information form the ALS data, a grid of 100 m^2 rectangular elementary sampling units (ESU) was established. Next, for each ESU the woody canopy cover K_{Lidar} was calculated as

$$K_{Lidar} = \sum (P_{1..4} \mid h_P \geq 2) / \sum P_{1..4}, \qquad (1)$$

where $P_{1..4}$ identifies a pulse return in the ALS data and h_P is the pulse return height from the ground level. The final outcome of the procedure was K_{Lidar} raster map where each ESU corresponded to a particular pixel. The raster data were then processed in GRASS (GRASS, 2013).

The validation dataset was established using a false colour ortophoto from spring 2011. Tree canopy boundaries were digitized for 442 ESUs located in a large abandoned afforesting field using QGIS (QGIS, 2013) spatial freeware tools. The boundaries of tree the crowns and of the tree canopy were determined by visual interpretation. Different size trees and tree groups were present in the area. For each ESU, the ortophoto based canopy cover K_{CIR} was calculated as $K_{CIR} = S_{canopy} / 100$, where S_{canopy} is the area (m^2) of the canopy according to the canopy map.

The final step in the mapping procedure was the conversion of K_{Lidar} raster map into polygons of afforested patches. For this purpose the raster map was binarised by applying an expert guess based discrimination level $K_{Lidar} \geq 0.25$ and then converted into vector polygons using GDAL spatial data processing library (GDAL, 2013).

Results and Discussion

Canopy cover is a simple variable by its general definition. Usually tree crowns are considered as opaque, but this assumption does not always hold. As a result, canopy cover can be underestimated e.g. from ALS data. Lang (2010) analysed options to estimate canopy cover from ALS data and found that the results are influenced by several factors. The estimates depend mainly on the choice of pulse return number (several returns can be detected from a single emitted pulse) and on the reference height. The number of returns for stable canopy cover estimates must be 100−200 in an observation area according to Rautiainen *et al*. (2005). In this study, however, a compromise was made in respect to spatial resolution, since there were only 34−60 returns per 100 m^2 ESU. Increasing the elementary sampling unit size would produce more rugged boundaries. The ALS based canopy cover is also affected by errors in DEM, since the reference height is measured from estimated ground level. In the ortophoto based validation dataset crown projections were closed polygons. On the other hand, sheltered trees in shadows could have been missed on the ortophoto.

A comparison of ALS and ortophoto based canopy cover estimates indicated a good agreement since the coefficient of determination of the linear model was $R^2 = 0.795$, model residual standard error (RSE) was 0.116 and the root-mean-square error (RMSE) between the two estimates was 0.156 (Figure 2). The K_{Lidar} was slightly

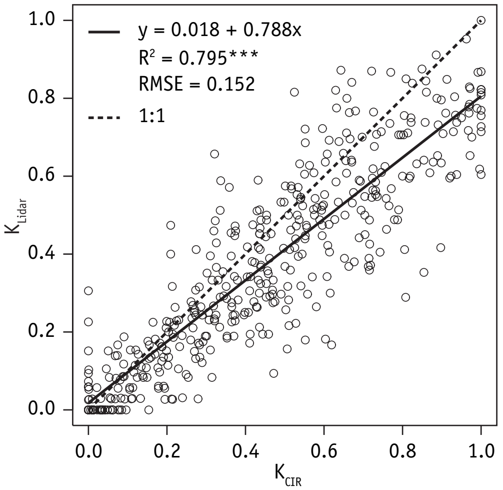

Figure 2. The comparison of canopy cover estimates from false colour composite ortophotos ($K_{CIR} = x$) with the canopy cover estimates from airborne lidar data ($K_{Lidar} = y$). Each point corresponds to a 100 m^2 observation area.

Joonis 2. Valevärvi-ortofotodelt hinnatud katvuse ($K_{CIR} = x$) ja lennukilidari andmetest hinnatud katvuse ($K_{Lidar} = y$) võrdlus. Üks punkt joonisel vastab 100 m^2 suurusele alale looduses.

underestimated compared to the K_{CIR} probably due the inherent differences in both methods. The lidar measurements were carried out one year before the acquisition of the ortophoto. It is not clear of how much this time difference could influence the K_{Lidar} underestimation compared to the K_{CIR}. However, the R^2 and the RMSE of the linear dependence of the K_{Lidar} on K_{CIR} (Figure 2) and visual checks prove that ALS data can be used for mapping woody plant cover in agricultural areas (Figure 3).

The proposed woody plant cover mapping method is fast and can be applied using freely available software tools. There is virtually no need for additional fieldwork which makes the method cost-effective. A drawback of the method is its inability to distinguish between buildings and woody plants. The reference height in canopy cover estimation can be changed to map lower or higher plants. The elementary sampling unit size can be decreased when higher pulse density ALS data will become

Figure 3. Vector boundaries of individual 100 m^2 areas having lidar based canopy cover $K_{Lidar} \geq 0.25$. The background image is from the Estonian Land Board public access server (www.maaamet.ee).

Joonis 3. Vektorkaardi näide aladest, kus iga 100 m^2 suuruse algse vaatlusühiku piires oli võrastiku katvus $K_{Lidar} \geq 0,25$. Taustapilt pärineb Eesti Maa-ameti avalikust geoportaalist (www.maaamet.ee).

available to produce smoother boundaries of woody plant cover patches. The observation units can also be land parcels, but then an assumption of the single land use category within each land parcel has to be made. On the other hand, the independent observation units allow us to analyse the pattern and location of the woody plant cover.

The Estonian Land Board has already finished wall-to-wall ALS data cover (www.maaamet.ee) for a country wide DEM development. ALS data have also been collected during flights for forest inventory. Automated batch processing of these datasets is possible; however, the flights for DEM data collection have been made during the time of rapid foliage development when the canopy transparency decreases and as a result the ALS data based canopy cover estimates increase. This change can be accounted for, but further studies are required to develop the corresponding models.

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References

Adermann, V. 2003. Eesti metsad 2002. (Estonian forests 2002). Tallinn, Metsakaitse- ja Metsauuenduskeskus. (In Estonian).

Adermann, V. 2005. Eesti metsad 2004. (Estonian forests 2004). Tallinn, Metsakaitse- ja Metsauuenduskeskus. (In Estonian).

Adermann, V. 2006. Eesti metsad 2005. (Estonian forests 2005). Tallinn, Metsakaitse- ja Metsauuenduskeskus. (In Estonian).

Adermann, V. 2009. Eesti metsad 2008. (Estonian forests 2008). Tallinn, Metsakaitse- ja Metsauuenduskeskus. (In Estonian).

Adermann, V. 2010. Development of Estonian National Forest Inventory. – Tomppo, E.; Gschwantner, Th.; Lawrence, M.; McRoberts, R.E. (eds.). National Forest Inventories. Springer, 171−184.

Adermann, V. 2012. Eesti metsad 2010. (Estonian forests 2010). Tallinn, Keskkonnateabe Keskus. (In Estonian).

GDAL. 2013. Geospatial Data Abstraction Library. [WWW document]. – URL http://www.gdal.org. [Accessed September 10, 2013].

GRASS. 2013. GRASS GIS. [WWW document]. – URL http://grass.osgeo.org. [Accessed September 10, 2013].

Jennings, S.B., Brown, N.D., Sheil, D. 1999. Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. – Forestry, 72, 59–73.

Kohava, P. 2000. Eesti metsad 1999. (Estonian forests 1999). Tallinn, OÜ Eesti Metsakorralduskeskus. (In Estonian).

Kohava, P. 2001. Eesti metsad 2000. (Estonian forests 2000). Tallinn, OÜ Eesti Metsakorralduskeskus. (In Estonian).

Korhonen, L., Korhonen, K.T., Rautiainen, M., Stenberg, P. 2006. Estimation of forest canopy cover: a comparison of field measurement techniques. – Silva Fennica, 40(4), 577–588.

Korhonen, L. Korpela, I., Heiskanen, J., Maltamo, M. 2011. Airborne discrete-return LIDAR data in the estimation of vertical canopy cover, angular canopy closure and leaf area index. – Remote Sensing of Environment, 115, 1065–1080.

Lang, M. 2010. Estimation of crown and canopy cover from airborne lidar data. – Forestry Studies / Metsanduslikud Uurimused, 52, 5–17.

Mander, Ü., Palang, H. 1994. Changes of landscape structure in Estonia during the Soviet period. – GeoJournal, 33(l), 45–54.

McGaughey, R.J. 2012. FUSION/LDV: Software for LIDAR Data Analysis and Visualization. May 2012 – FUSION Version 3.10. United States Department of Agriculture Forest Service Pacific Northwest Research Station.

Morsdorf, F., Kötz, B., Meier, E., Itten, K.I., Allgöwer, B. 2006. Estimation of LAI and fractional cover from small footprint laser scanning data based on gap fraction. – Remote Sensing of Environment, 104, 50–61.

Næsset, E. 1997. Determination of mean tree height of forest stands using airborne laser scanner data. – ISPRS Journal of Photogrammetry & Remote Sensing, 52, 49–56.

Peterson, U., Aunap, R. 1998. Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat MSS imagery. – Landscape and Urban Planning, 41(3-4), 193–201.

Peterson, U., Püssa, K., Liira, J. 2004. Issues related to delineation of forest boundaries on Landsat Thematic Mapper winter images. – International Journal of Remote Sensing, 25, 5617–5628.

Pärt, E. 2005. Metsavarud. – Aastaraamat 2004. (Forest resources. – Yearbook Forest 2004). Tartu, Metsakaitse- ja Metsauuenduskeskus, 1–46. (In Estonian).
Pärt, E., Adermann, V., Lepiku, P. 2008. Metsavarud. – Aastaraamat 2007. (Forest resources. Yearbook Forest 2007). Tartu, Metsakaitse- ja Metsauuenduskeskus, 1–44. (In Estonian).
Pärt, E. Adermann, V., Lepiku, P. 2009. Metsavarud. – Aastaraamat 2008. (Forest resources. – Yearbook Forest 2008). Tartu, Metsakaitse- ja Metsauuenduskeskus, 1–40. (In Estonian).
QGIS. 2013. Quantum GIS. [WWW document]. – URL http://www.qgis.org. [Accessed September 10, 2013].
Raudla, H. 2010. Eesti põllumajandus, maaelu, kalandus. (Estonian agriculture, rural life and fisheries). Tallinn, Põllumajandusministeerium. (In Estonian).
Rautiainen, M., Stenberg, P., Nilson, T. 2005. Estimating canopy cover in Scots pine stands. – Silva Fennica, 39(1), 137–142.
Vain, A., Kaasalainen, S., Pyysalo, U., Krooks, A., Litkey, P. 2009. Use of naturally available reference targets to calibrate airborne laser scanning intensity data. – Sensors, 9, 2780–2796; DOI:10.3390/s90402780.
Viilup, Ü. 2002. Metsavarud. – Aastaraamat Mets 2001. (Forest resources. – Yearbook Forest 2001). Tartu, Metsakaitse- ja Metsauuenduskeskus, 1–35. (In Estonian).
Vipper, H., Masso, V., Kuill, T., 1996. Maade söötijätmine teeb Eestile kahju. (Abandonment of land makes harm to Estonia). – Agriculture, 9, 6–7.

Lihtne meetod aerolidari andmete põhjal puitttaimestiku kaardistamiseks mahajäetud põllumaadel

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Kokkuvõte

Suurimad hiljutised muutused Eestis põllumajandusliku maa kasutuses toimusid peale Nõukogude Liidu kokkuvarisemist, kui sööti jäeti kuni kolmandik põldudest (Peterson ja Aunap, 1998). Põllumajandusliku maa kasutamise kohta Eestis praegu on erinevaid hinnanguid. Statistilise metsainventuuri (SMI) hinnangutel on viimase kümnendi jooksul põllumajandusliku maa pindala püsinud stabiilne, kuid selle sees on kasvanud haritava maa osakaal looduslike rohumaade arvelt (joonis 1). Riikliku statistika kokkuvõtetest (Randla, 2010) selgub, et 2009. aastal kasvatati põllukultuure 566,6 tuhandel hektaril, samas aga SMI pakub haritava maa pindalaks 1105,6 tuhat hektarit samal aastal. Nendest hinnangutest võiks ehk järeldada, et umbes pool haritavast maast oli 2009. aastal kasutuses kultuurrohumaana, kuid mõlemad hinnangud põhinevad erinevatel meetoditel ning ka definitsioonid võivad erineda. Põllumajandusliku maa üle peab Eestis arvestust ka Põllumajanduse Registrite ja Informatsiooni amet (PRIA). PRIA põllumajandusmaade registri ja taotluste andmebaasi alusel deklareeriti 2003. aastal 1232,0 tuhat ha põllumajanduslikku maad, aga 2009, 2010 ja 2011. aastal esitati toetuste taotlusi vastavalt 1127,3, 973,0 ja 952,7 tuhande hektari kohta. Aktiivsest kasutusest välja jääv põllumajanduslik maa kattub arvatavasti metsaga.

Käesoleva töö eesmärgiks oli koostada olemasolevatel teadmistel põhinev metoodika põldudele tekkiva puittaimestiku kaardistamiseks. Metoodika põhineb taimkatte katvuse K_{Lidar} (1) hindamisel aerolidari andmete põhjal (Lang, 2010) ja protseduuri väljundiks on puittaimestikuga alade välispiirid edasiseks ruumianalüüsiks sobiva numbrilise kaardina.

Meetodi testimiseks valiti Järvselja Õppe- ja Katsemetskonna lõunaosas asuvad põllud, mille kohta oli olemas 2010. aasta metsakorralduse jaoks tehtud lidarmõõdistuse andmed. Edasiseks analüüsiks jagati katseala 100 m^2 suurusteks vaatlusaladeks. Lidarandmetest arvutati katvus kahe meetri kõrgusel maapinnast, sest enamik põllukultuure ja rohttaimed nii kõrgeks ei kasva. Tulemust võrreldi 422 vaatlusalal 2011. aasta ortofoto alusel ekraanilt digitud võrapiiride järgi saadud katvusega K_{CIR} (joonis 2). Kahe sõltumatu meetodi järgi hinnatud katvuste lineaarseos oli tugev, mida näitasid R^2 = 79,5%, mudeli jääkviga RSE = 0,116 ja keskmine ruutviga RMSE = 0,156. Lidarandmete põhjal arvutatud katvus oli veidi väiksem ortofotolt saadud katvuse hinnangust meetodite omapärade ja andmestike ajalise erinevuse tõttu. Lidarandmete põhjal koostati 10 m suuruse ruumilise lahutusega rasterkaart, millelt piiritleti puittaimestikuga kaetud alad kasutades ekspertarvamusel põhinevat reeglit $K_{Lidar} \geq 0{,}25$ (joonis 3).

Kirjeldatud meetod on lihtne ja põhineb juba testitud andmetöötlusvõtete kombineerimises. See tagab samas meetodi usaldusväärsuse praktilistes rakendustes. Meetod ei nõua eraldi välitöid ja on realiseeritav vabavaras olevate protseduuride abil. Katvuse hinnanguid võib arvutada ka põlde 100 m^2 alade asemel vaatlusühikuteks võttes, kuid siis tuleks eeldada, et põllud ei ole osaliselt kasutuses. Põldudest sõltumatud vaatlusalad aga võimaldavad analüüsida tekkiva puittaimestiku rinde paiknemist põllu piires. Kogu Eesti kohta on käesolevas töös pakutud meetodi rakendamine samuti võimalik, sest algandmed on Maa-amet kogunud rutiinsete kaardistuslendude käigus. Enne suuremahulisi andmetöötlusprotseduure tuleks siiski testida, kuivõrd hästi sobivad kevadisel lehtede kiire arengufaasi ajal aerolidariga tehtud mõõtmised puittaimestiku katvuse hindamiseks. Tulemusena tekkivat metsakaarti saab edasi rakendada ruumiandmete analüüsis koos muude digitaalsete kaartidega, et selgitada täpsemalt põllumajandusliku maa metsastumise määra.

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