

IMPACT OF AGRICULTURAL LANDHOLDING SIZE ON THE LAND FRAGMENTATION

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Abstract

Land fragmentation is a problem in Europe, and Estonia is not an exception in this respect. Parcel size is widespread characteristic to describe the level of fragmentation. The aim of the study is to find out if there is difference of fragmentation among different groups of landholdings by size. In order to characterise land fragmentation, were calculated the Januszewski and Schmook indexes, average parcel size and average distance from the gravity centre of each landholding to its parcels. Results showed a high level of fragmentation of Estonian agricultural landholdings. There is a high variety of fragmentation inside and among the investigated groups. The average value of Januszewski index for all groups is 0.626, and the average value of Schmook index for all groups is 0.462. The average parcel size for all groups is 7.02 hectares and average distance from the gravity centre of each landholding to its parcels for all groups is 1.57 kilometres.

Key words: Januszewski index, Schmook index, parcel, arable land.

Introduction

The rational use of agricultural land is influenced by land use limitations. One of the obstacles for agricultural development is land fragmentation (Hristov, 2009; Austin et al., 2012; Vijulie et al., 2012). Land fragmentation is defined as the situation in which a single farm or ownership consists of numerous spatially separated plots (Bentley, 1987). Dominant problem associated with land fragmentation is the small size, irregular shape and dispersion of parcels (Dijk, 2000; Gonzalez et al., 2007; Demetriou et al., 2013).

Increasing population entails fall in the landholding size and fragmentation into small parcels (Bizimana et al., 2004; Aslan et al., 2007). Parcel size is the primary characteristic to describe the land use conditions and to evaluate the land fragmentation. The simplest method is to calculate the average size of the landholding or parcel. Although, this method is considered to be easy and comfortable, the main disadvantage is the fact that it does not describe the distribution of parcels by size (Demetriou et al., 2013). When landholdings are fragmented into several small parcels which are spatially scattered and the distance from the farmhouse is varying, it hampers agricultural development in many ways (Niroula and Thapa, 2005; Kakwagh et al., 2011).

The landholding or parcel size and its influence on land fragmentation and/or agricultural productivity is an overall problem around the world. For example, in Nigeria and China, the impact of land fragmentation and landholding size has been investigated to rice farming. Ben-Chendo et al. (2014) found out that landholding size of the rice farmers is relatively small and it can discourage the practice of rice farming. Therefore, the option would be enhancement of landholding size. Tan et al. (2008) study showed that farmers with more and smaller plots tend to

use fewer modern technologies and reduction of the average distance to plots and an increase in farm size decreases the total production costs per ton. Also, researchers found that solution would be consolidation of landholdings into holdings consisting of fewer plots with larger average size. Several authors agree that small landholdings and tiny parcels affect agricultural development negatively and land consolidation would be the option to solve these problems (e.g. Kopeva et al., 2002; Travnicek, 2002; Niroula and Thapa, 2005; Pašakarnis et al., 2012).

In Estonia, the land fragmentation has been briefly investigated, but there are some studies that can be named. For example, Maasikamäe (2005) analysed the aspects of land fragmentation (average parcel size, the shape of the parcels and land use conditions, internal fragmentation) in general. Aasmäe and Maasikamäe (2014) investigated the existence and extent of internal fragmentation of agricultural parcels. As land fragmentation is an ongoing process, investigation of landholding structure in Estonia is vital to get more complex information about the land use patterns. The study was carried out among Estonian agricultural landholdings. The aim of the study is to find out if there is difference of fragmentation among different groups of landholdings by size. Research tasks are: a) to evaluate land fragmentation by calculation of Januszewski and Schmook indexes; b) to compare land fragmentation characteristics in different groups.

Materials and Methods

In the study, data from Estonian Agricultural Registers and Information Board (ARIB) was used. The data for the study were digital map of borders of parcels on what the subsidy was applied for in 2014. Landholdings were divided into four groups based on the area of landholding. In this study, each application area was considered as one landholding. The group

formation criterion was based on the summary report of farmers' economic indicators of 2013 (Aamisepp et al., 2014). Groups are as follows: less than 40 hectares; 40 to 100 hectares; 100 to 400 hectares and more than 400 hectares. In this way large and small landholdings were distinguished. Landholding was considered to be large if the total area of landholding was 400 hectares or more. In further text the groups are named A, B, C and D.

The study consists of three steps: firstly, to evaluate land fragmentation of Estonian landholdings; secondly, to calculate average distance from the gravity centres of each landholding to its parcels; thirdly, to compare land fragmentation characteristics in different groups, based on the area of landholdings. All calculations were made in GIS environment with ArcGIS software.

To form the groups, the total area of each landholding was calculated using the Summary Statistics tool in ArcGIS. The main characteristics of land fragmentation were calculated for each group: average Januszewski index, average Schmook index, average parcel size and average distance from the gravity centre of each landholding to its parcels. In order to evaluate land fragmentation, the Januszewski index (Januszewski 1968), whose formula is shown in equation 1 and reciprocal of Schmook index, whose formula is shown in equation 2 were calculated. In further text the reciprocal of Schmook index is called just Schmook index. The Januszewski index is the ratio of the square root of the total area of landholding to the square root of the sum of the areas of the land parcels. It changes in the interval from zero to one. Low index value indicates higher fragmentation.

$$K_j = \frac{\sqrt{S}}{\sum \sqrt{s_i}} \quad (1)$$

where

K_j is the Januszewski index,
 S is the total area of the landholding,
 s_i is the area of i -th parcel.

The Schmook index is the ratio of the area of one landholding to the area of imaginary polygon which circumscribes all of the parcels of that holding. The index also ranges from zero to one. It equals to one if the landholding consists of a single compact unit of land. When the parcels are highly fragmented index value approximate to zero.

$$k = \frac{\sum s_i}{S} \quad (2)$$

where

k is Schmook index,
 S is the imaginary polygon drawn around the area of land parcels,
 s_i is the area of i -th parcel.

For calculating the area of imaginary polygon (S) which circumscribes all of the parcels of one landholding was used the Minimum Bounding Geometry tool in ArcGIS. To create the polygons, the command Convex Hull was used and then the area for each constructed polygon was calculated. Figure 1 demonstrates the Convex Hull for one farmer's land use.

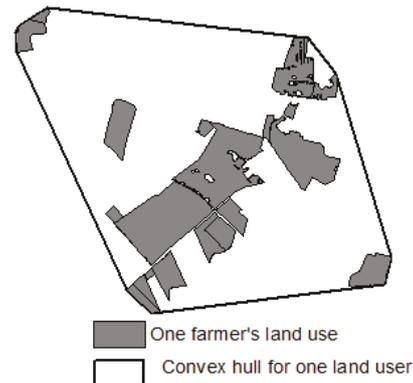


Figure 1. Land parcels of one landholding and surrounding Convex Hull for them.

The next task was to calculate the average distance from the gravity centre of each landholding to its parcels. The Mean Centre tool in ArcGIS was used for calculation of gravity centres for each landholding. Then, the Pythagoras's formula was used to calculate the distance between the gravity centre and the parcels for each landholding.

The average parcel size was calculated for all investigated groups of landholdings. To find out if there is statistically significant difference between mean areas of parcels of the groups of landholdings, Kruskal-Wallis Test was used. This test allows comparing two or more samples that are independent.

Results and Discussion

The main results of the study are presented in Table 1 and Table 2. Landholdings are divided into four groups depending on the area of landholding. Table 1 shows that the number of investigating landholdings is 17 104. The total area of landholdings is 916 009.3 hectares which consist of 129 598 parcels.

The data in Table 1 show that the ratio of number of landholdings varies notably among groups. The number of landholdings of group A (< 40 hectares) form 81% of the total land use. In group B the ratio of the number of landholdings is 9 times smaller than in group A. The ratio of number of landholdings in group C and D is respectively 11 and 29 times smaller compared to group A.

The ratio of the total area of landholdings varies among groups. Landholdings of the group D (\geq 400 hectares) form 47.2% of the total area of land use.

Table 1

General description of investigated landholdings

Characteristics	Landholding size(ha)				Total or average
	< 40	40 - < 100	100 - < 400	≥ 400	
The number of landholdings	13 859	1485	1277	483	17 104
Ratio of the number of landholdings by groups (percent)	81.0	8.7	7.5	2.8	100.0
Total area of landholdings by groups (ha)	140 447.4	93 272.8	249 960.9	432 328.2	916 009.3
Ratio of total area of landholdings by groups (percent)	15.3	10.2	27.3	47.2	100.0
Average landholding size (ha)	10.1	62.8	195.7	895.1	53.6
The total number of parcels by groups	44 279	16 214	33 403	35 702	129 598
Ratio of total number of parcels by groups (percent)	34.2	12.5	25.8	27.6	100.0
Average number of parcels per landholding	3.2	10.9	26.2	73.9	7.58

Followed by landholdings of the group C (100 - < 400 hectares) which form 27.3% of the total area of land use. Landholdings of the groups A and B (< 40 - < 100 hectares) form 25.5% of the total area of land use. The total area of landholdings of the group A is three times smaller compared to the group D. Comparing the number of landholdings and total area of landholdings in each group one can see that the number of small landholdings (all landholdings less than 400 hectares) are dominating, but the difference between the total area of small and large landholdings is only 5.6%.

The average landholding size by groups varies from 10 to 895 hectares. The difference between the group A and the group B is six times and the difference between the group A and group C is 19 times. The most remarkable difference is between the group A and D, about 88 times. The average landholding size for all groups is 53.6 hectares.

The ratio of the number of parcels does not vary considerably among groups. The biggest difference is between the group A and the group B, about three times. One can see some differences in the average number of parcels per landholding. In the group A landholding on average consists of 3.2 parcels, in the group B and C the respective values are 10.9 and 26.2 parcels per landholding. The landholdings of the group D consist on average of 73.9 parcels. This is about 25 times bigger compared to the group A. The average number of parcels per landholding for all groups is 7.58.

The main characteristics of land fragmentation are presented in Table 2. The average parcel size increases among the groups. For all groups the average parcel size is 7.02 hectares. Average parcel size ranges from 3 to 12 hectares. The difference between the groups A and D is almost four times. The maximum parcel size of the group A is about three times smaller than in the group C and five times smaller than in the group D.

Also, there are big differences in the minimum size of the parcel, for example the minimum parcel size in the group A is 22 times smaller than in the group D.

The average distance from the gravity centre to the parcels for all groups is 1.57 kilometres. The average distance from the gravity centre to the parcels varies from 1 to 6 kilometres. The minimum distance varies from 0.01 to 1.04 kilometres and the maximum distance varies from 87.34 to 135.59 kilometres. In the groups A, B and C were 3727 landholdings that consist of only one parcel. This means that it was not possible to calculate the average distance and therefore the corresponding value was zero.

The average value of Januszewski index for all groups is 0.626. The comparison of the minimum and maximum values of the Januszewski index in all groups shows a high variety of land fragmentation. The degree of fragmentation is remarkably smaller in the group A where the landholding size is less than 40 hectares, but holdings on an average consist of three parcels. Landholding size in the other groups (B, C, D) is bigger, but also the number of parcels in landholding is 11 to 74 times bigger compared to the first group. Therefore, the value of Januszewski index decreases as the number of parcels increases.

The average value of Schmook index shows the spatial dispersion of parcels. The average value of Schmook index for all groups is 0.462. For some landholdings the minimum value of Schmook index is very small (approximate to zero), difference between minimum and maximum values is up to 1000 times. The spatial dispersion of parcels is smaller in the group A where the value of the Schmook index is higher. The degree of fragmentation increases when the landholding size is more than 40 hectares. Also, the average distance increases when the landholding size is more than 40 hectares which indicates higher spatial dispersion.

Table 2

Average field size, average distance to the centre of gravity and average values of Januszewski and Schmook’s indexes by the size of landholding

Characteristics	Landholding size (ha)				Total or average
	< 40	40 - < 100	100 - < 400	≥ 400	
The number of landholdings	13 859	1485	1277	483	17 104
Parcel size (ha)	Avg	3.17	5.75	7.48	12.11
	Min	0.14	1.02	1.94	3.12
	Max	38.06	72.50	102.31	197.60
Distance of the centre of gravity (km)	Avg	1.03	2.86	4.12	6.33
	Min	0.01	0.15	0.32	1.04
	Max	135.59	89.08	87.34	91.21
Januszewski index	Avg	0.702	0.390	0.250	0.149
	Min	0.177	0.117	0.101	0.065
	Max	1.00	1.000	1.000	0.653
Schmook’s index	Avg	0.534	0.212	0.115	0.105
	Min	0.000	0.000	0.000	0.000
	Max	1.000	0.956	0.873	0.702

Kruskal-Wallis Test was used to find out if there is statistically significant difference between mean areas of parcels of the groups of landholdings. The results of the test (Figure 2) showed that the difference between the investigated groups is statistically significant. In the Figure 2, one can see that confidence intervals do not overlap and this means that there is a significant difference between groups. Also, there are big differences between minimum and maximum size of parcels. Parcel size varies from 0.14 to 197.60 hectares. The difference between the minimum parcel

size of the groups A and D is about 22 times. The difference between the maximum parcel size of the groups A and D is 5 times.

The results showed that there is a high level of fragmentation of agricultural landholdings. But the current study did not reflect all aspects of fragmentation. Therefore, the further study of spatial characteristics (e.g. parcels shape and internal fragmentation) is needed. For example an important research question in future is spatial location of landholdings in respect of each other.

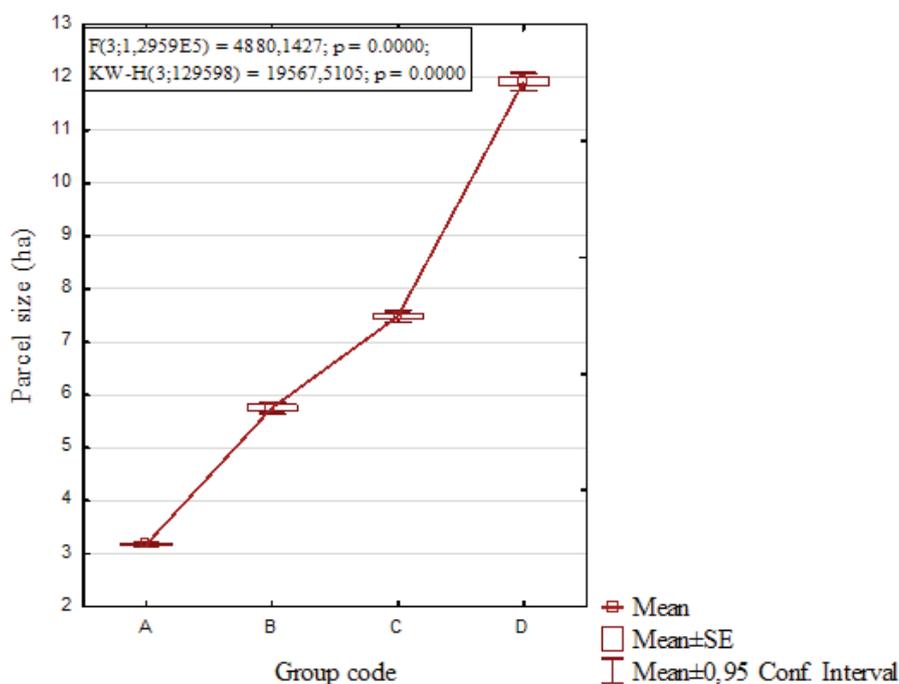


Figure 2. Comparison of mean areas of parcels by investigated groups of landholdings.

Conclusions

1. Results showed that agricultural landholdings of Estonia are fragmented and spatially dispersed. The average value of Januszewski index for investigated landholdings is 0.626. The average value of Schmook index for investigated landholdings is 0.462.
2. Landholdings which size is more than 40 hectares are highly fragmented and spatially dispersed. The average value of Januszewski index is less than 0.400. The average value of Schmook index is less than 0.200.
3. The average parcel size for investigated landholdings is 7.02 hectares. Study showed that there is statistically significant difference between mean areas of parcels by investigated groups of landholdings. Parcel size varies from 0.14 to 197.60 hectares.
4. The average landholding size for investigated landholdings is 53.6 hectares. It varies notably among the groups of landholdings from 10 to 895 hectares.
5. The number of landholdings which are less than 400 hectares form 97.2% of the total land uses, while they manage 52.8% of the total area of investigated landholdings. The number of landholdings that are more than 400 hectares form 2.8% of the total land uses, while they manage 47.2% of the total area of investigated landholdings. This clearly shows that land is concentrated to large producers.

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