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MARGINAL ARABLE FIELDS IN SWEDEN – AREAS, SHAPES, TRANSPORT DISTANCES AND TIME DEMAND AND COSTS FOR MACHINE OPERATIONS

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Abstract

Of the total arable land area of 2.6 million hectares in Sweden in the year 2017, the acreage of 'marginal' or passively used land, such as fallow, low-intensity ley, etc., may amount to half a million hectares. By contrast, the future demand for land for the production of fuels and industrial products is expected to increase. The aims of this study were to characterise arable marginal land in four municipalities in Sweden with regard to e.g. field size, field shape and remoteness, and to compare the time demand and costs for machine operations in 'marginal' fields and in 'normal' fields. Field work was simulated with a model that mimics the in-field driving pattern of machines.

The results highlighted the fact that what is considered a small field in one part of the country may be considered a 'large' field in another part. Furthermore, it was shown that the average parcel area for fallow and low-intensity ley culture was in the range 1-2 ha, which is smaller than for 'normal' fields with e.g. cereal crops. Marginal fields often have a more irregular shape, and they are often more distant, but this was also dependent on region and type of landscape. The simulations showed that field area and field shape have significant impacts on time demand and machinery costs. For example, it was shown that the time demand and costs rise steeply for fields smaller than about 2 ha as a result of more time, relatively seen, spent on e.g. turnings.

Keywords: marginal arable land, area, shape, machinery, costs.
JEL Codes: Q15.

Introduction

The total area of cultivated arable land in Sweden has decreased by about 13% from the year 1982 (2.95 million ha) to the year 2017 (2.57 million ha) (Swedish Board of Agriculture, 2018a). A large part of this area reduction can be referred to land that has been abandoned due to low economic profitability. Of the area in use in the year 2017, 0.16 million ha were fallow land (Figure 1). The area of fallow has varied considerably in recent decades as a result of e.g. changing economic conditions and regulatory policies. Hundreds of thousands of hectares of ley are also underutilized or cultivated at low intensity. For example, Jonsson (2008) estimated the excess cultivation area of ley to be 0.2-0.3 million ha. Consequently, the current total acreage of 'marginal' land may amount to about half a million hectares in Sweden.

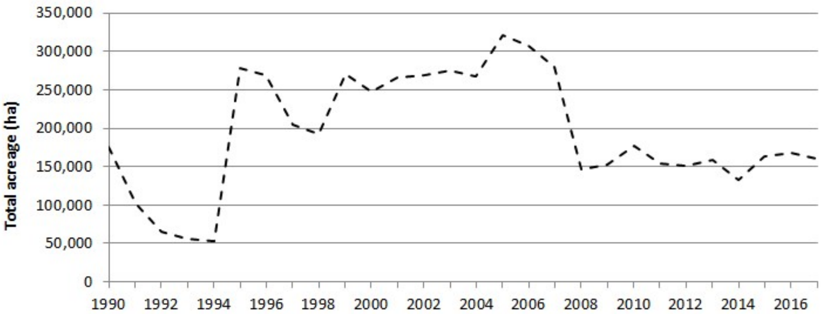

Figure 1. The area of fallow land in Sweden from 1990 to 2017
(Source: Swedish Board of Agriculture, statistics database
http://www.jordbruksverket.se/omjordbruksverket/statistik.4.67e843d911ff9f551db80003060.html)

The demand for renewable biomass for the production of fuels and industrial products is expected to increase. In that case, the total need of arable land for the production of food, feeding-stuff, fuels and industrial products will increase. For 'marginal' land, the cultivation of dedicated energy and industrial crops may be an alternative (Mehmood et al., 2017; Liu et al., 2017).

The term 'marginal agricultural land' is often used in a "subjective sense for less-than-ideal lands without sufficient specificity" (Richards et al, 2014). Normally, however, it is used in an economic perspective, meaning that the economic profitability of crop cultivation is too low (Shortall, 2013). Factors such as soil fertility, field size, field shape, remoteness, stoniness and wetness have crucial impacts on the economic profitability. Thus, what is considered as marginal land is relative with respect to e.g. geographical location (Richards et al, 2014).

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In most calculations of cultivation costs, 'standard' machine capacities are used, independent of the real variations in size and shape of fields, yield levels, machines' real operating speeds and effective working widths, etc. (Nilsson et al., 2014). Marginal land often consists of small and irregular fields, for which the time demand for different operations is higher than for 'normal' fields. Thus, there is a risk of cost underestimations if the machine capacity is based on standard values. Transport costs may also be of greater significance for marginal fields, relatively seen, because the fields often are small and remote (Nilsson et al., 2014).

The aims of this study were to characterise arable marginal land in four municipalities (Svalöv, Ronneby, Vingåker, Skellefteå) in Sweden with regard to field size, field shape, distance to farm and location with respect to level of standard yields. Furthermore, field work was simulated for different field sizes and field shapes in order to compare the time demand and costs for machine operations in 'marginal' fields and in 'normal' fields.

Materials and methods

Marginal field characterisation

The definition of a "marginal field" in this study was based on what the farmers considered as arable land with marginal or even negative economic profitability. For example, if a farmer chooses to have fallow in a specific field, it is likely that the economic profitability is lower in that field compared to a field in which sugar beets are cultivated. All parcels for which the farmers applied for the direct payment support in the so-called SAM applications in 2016, and for which the crop codes were 49 (here denoted as low-intensity ley), 60 (fallow) and 77 (border strips; in most cases grassy land), were considered as marginal fields in this study (for a more detailed description of crop code definitions, see the Swedish Board of Agriculture (2018b)).

Data on such parcels (area, perimeter, block number) were obtained from The Swedish Board of Agriculture for the municipalities Svalöv (55°55′0″N 13°7′0″E), Ronneby (56°12′25″N 15°16′45″E), Vingåker (59°2′38″N 15°52′21″E) and Skellefteå (64°45′8″N 20°55′40″E). These municipalities were assumed to represent different regions in Sweden with different cultivation conditions regarding climate, soil fertility, type of landscape, farm company size and structure, etc.

To describe the shape of fields investigated, the so-called shape index (*SI*) was used (de Clercq et al., 2006; Cousins and Aggemyr, 2008; Nilsson et al., 2015). *SI* can be calculated by

$$SI = P/(2\sqrt{(\pi A)}) \quad (1)$$

where P - perimeter (m)
A - field area (m^2).

The value of *SI* has its minimum for a circular field (*SI*=1). The more the field shape deviates from a circular area, the higher the value will be, and the more 'irregular' the field shape may be. For a quadratic and a rectangular field with length:width ratios of 1:1 and 4:1, *SI*=1.13 and *SI*=1.41, respectively.

All agricultural blocks are identified by a 11-digit number, of which the first seven digits describe the position of the block center in the national RT90 geographical coordinate system. In the RT90 system, each grid square is 1.0 km x 1.0 km, i.e. 100 ha. The block numbers and the RT geographical system were used in a simplified method to estimate the transport distances between parcels and a location supposed to contain the farm (machinery/holding) center. Firstly, the farm center was assumed to be located in the center of the square in which each farmer had the highest concentration of land area. Then, the Euclidian distance to each parcel was calculated according to its associated block number describing the grid square in which it was located.

The extent to which marginal fields are located in different standard yield areas was investigated. For example, it can be expected that marginal fields are more common in low-yielding standard yield areas. All agricultural blocks have a specific regional code describing which parish the block center is located in. These codes were combined with data on which standard yield area each parish belongs to (Statistics Sweden, 1992; Statistics Sweden, 1998) and standard yield data for spring barley (Statistics Sweden, 2016). Spring barley was chosen as a reference crop as it is cultivated in most parts of Sweden. Note that the data obtained not specify the soil fertility in a specific field, but rather the average yield for a specific crop in a specific area.

Simulation model

A simulation model was built in the Arena/SIMAN software environment (Kelton et al., 2007) in order to compare performance and costs of machine operations in fields with different areas and shapes. The model is a further development of the simulation model presented by Nilsson et al. (2014) and Nilsson et al. (2015). Arena/SIMAN is based on the dynamic discrete-event simulation approach (Kelton et al., 2007) and has animation facilities enabling the machine operations to be followed in detail on the screen. The machine operations were simulated in marginal fields with areas of 0.75 ha and 1.50 ha, having two different shapes (A and B; see Figure 2). These areas were chosen as almost half of all marginal fields in the municipalities investigated were covered in the interval 0.50-1.75 ha (cf. Figure 4). Shape A was assumed to represent fields under 'normal' conditions and shape B 'irregular-shaped' fields. Simulations were also performed for larger fields of shape A: 3.00 ha, 6.00 ha and 12.00 ha.

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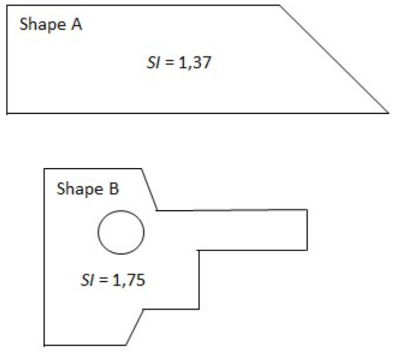

Figure 2. Field shapes used in the simulations

By means of the model, machine operations for cultivation of spring barley and ley were compared with regard to time demand and annual costs. For ley, the annual costs were based on a four-year rotation cycle; spring barley (nurse crop) – ley – ley – ley. The machines used in the operations are described in Table 1. Machines used for gathering and transport of grains and bales from the fields were not included.

Table 1. Machine operations and implements used in the simulations (exchange rate: €1.00 =10.3 SEK (25th May, 2018))

Operation	Implement	Working width[1)] (m)	Field capacity[2)] (ha/h)	Hourly machine costs[3)] (€/h)	Hourly tractor costs[4)] (kr/h)
Stubble cultivation	Heavy disc harrow	4.0	2.2	41.2	65.0
Ploughing	Rev. plough, 6 furrows, semi-mounted	2.0	1.2	35.3	65.0
Harrowing	Trailed harrow	8.0	5.0	37.3	65.0
Grain drilling	No combi-drill, 2200 L	6.0	3.0	33.7	58.6
Rolling	Roller	12.0	6.0	46.2	53.4
Fertiliser distribution	Mounted impl., 2500 L, computerised	24.0	6.0	20.7	53.4
Spraying	Trailed, 2500 L	24.0	7.0	47.8	53.4
Combine harvesting	Combine harvester, 20 ft	6.0	2.0	200.1	-
Mowing	Mower conditioner, mounted impl.	3.0	2.3	39.7	58.6
Windrowing	Rotary windrower	6.0	3.7	39.6	53.4
Silage baling	Roundbaler with wrapper	3.0	1.9[5)]	68.9	65.0

[1)] Assumed effective working width.
[2)] The capacity was assumed to be valid for fields with an area of 6.0 ha having shape A (Figure 2) (data from Maskinkalkylgruppen, 2017).
[3)] Hourly machine costs with ”normal” annual use (data from Maskinkalkylgruppen, 2017).
[4)] Hourly costs for two tractor sizes (90 kW och 110 kW) with ”normal” annual use (650 h/yr), working under ”normal” or ”heavy” work conditions. The costs include costs of tractor, driver and fuel (data from Maskinkalkylgruppen, 2017).
[5)] Corresponds to about 10 t dry matter (DM) per hour (Gunnarsson et al., 2007).

Several field efficiency factors were considered in the model; ‘install’ time before starting the work in the field, extra time for reduced driving speed in bends, time for turnings, time for acceleration, time for adjustments and stoppages (e.g. due to stone clearing or wrapping of bales), time for filling (seed, fertilisers, spraying water/chemicals) and emptying (threshed grain), finishing off time, etc. The reduced driving speed in bends were assumed to be dependent on the bending angle (Nilsson & Rosenqvist, 2018), and the time for turnings was dependent on type of turning; e.g. 15 sec. for a loop turn and 25 sec. for a reverse turn (excl. time for acceleration) (Witney, 1995; Nilsson & Rosenqvist, 2018). The acceleration of machines were assumed to be 890 m/min^2 for all operations. The time for deceleration was assumed to be negligible.

The model was calibrated by adjusting the model parameters driving speed in the pass, install time, finishing off time and stoppage time to reasonable values, resulting in a field capacity corresponding to the “normal” capacity data presented by Maskinkalkylgruppen (2017) (see Table 1). When calibrating the model, the capacity data of Maskinkalkylgruppen (2017) were assumed to be valid for a field of area 6.00 ha and shape A. Recommended ‘standard’ hourly costs, presented by Maskinkalkylgruppen (2017) (Table 1), were used in the cost calculations.

Results and discussion

Field areas, shapes, transport distances and yield levels

The average areas of all arable parcels in Svalöv, Ronneby, Vingåker and Skellefteå were 6.0 ha (total number of parcels: *n*=3404), 1.8 ha (*n*=3964), 3.1 ha (*n*=2443) and 2.0 ha (*n*=13284), respectively (note that such arithmetic mean values are comparatively low as the number of small parcels often is large). A 'typical' parcel area, here defined as the parcel area when half of the accumulated arable land is covered, was 13.1 ha, 3.3 ha, 6.0 ha and 3.1 ha, respectively. The total share of land area with low-intensity ley, fallow and border strips was lowest in Svalöv (Figure 3).

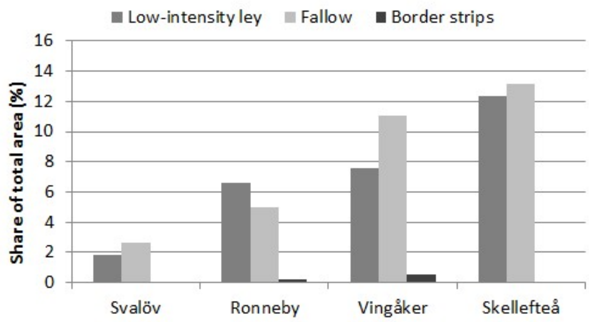

Figure 3. Share of low-intensity ley, fallow and broder strips in the municipalities investigated

The average areas of parcels with low-intensity ley and fallow were 1.0-2.0 ha for all municipalities (Figure 4). The average areas of border strips were 0.4-0.5 ha in Svalöv, Ronneby and Vingåker (there were no parcels with crop code 77 in the municipality of Skellefteå). For all other crops, the average areas were 2.0 ha in Ronneby and Skellefteå, 3.9 ha in Vingåker and 7.6 ha in Svalöv. As expected, border strip parcels were much more 'irregular' than other parcels (Figure 4). In Svalöv, there was a clear difference in *SI* between low-intensity ley/fallow and other crops. In Skellefteå, however, there does not seem to be a pronounced difference in shape between marginal fields and 'normal' fields.

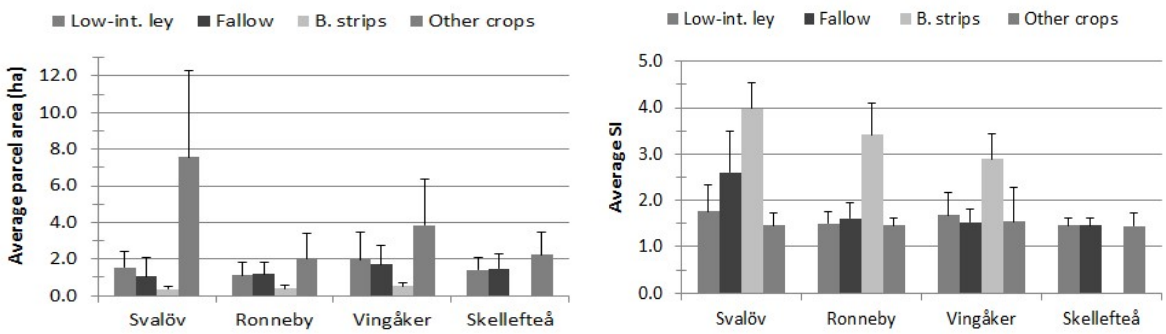

Figure 4. Average area and shape index of parcels with low-intensity ley, fallow, border strips and other crops in the municipalities of Svalöv, Ronneby, Vingåker and Skellefteå. The vertical lines show a half standard deviation

Parcels with fallow generally seem to be more remotely located than parcels with e.g. the category "other crops" (Table 2). Parcels with low-intensity ley, on the other hand, often have relatively short transport distances. A deeper analysis (Nilsson & Rosenqvist, 2018) revealed that parcels with low-intensity ley are more common on small farms than e.g fallow, relatively seen. Thus, the average transport distance for low-intensity ley will be relatively short as small farms in general have shorter transport distances than large farms.

Table 2. Average Euclidian transport distances (km) between farm centers and associated parcels with low-intensity ley, fallow, border strips and other crops

Field use	Svalöv	Ronneby	Vingåker	Skellefteå
Low-intensity ley	1.70	2.02	1.86	2.05
Fallow	1.83	2.18	2.04	2.75
Border strips	1.06	2.58	1.84	-
Other crops	1.80	1.56	1.41	2.27

The standard yield for spring barley was highest in a standard yield area in Svalöv (6550 kg/ha with a moisture content (m.c.) of 14%) and lowest in a standard yield area in Ronneby (2480 kg/ha; m.c. 14%) (Figure 5). In general, low-intensity ley was less common, relatively seen, in standard yield areas with high yield levels

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in the municipalities of Svalöv, Ronneby and Vingåker. However, in the municipality of Skellefteå, where almost 70% of the total arable land was located in a standard yield area with a yield level of 3060 kg/ha (m.c. 14%), low-intensity ley was more common in areas with higher standard yield levels. In most cases, the marginal fields were quite close to the average values of fields with the category "all crops". The largest difference was observed for the highest yield level area in Ronneby; 58% of the total arable area was located here, whereas the shares of low-intensity ley, fallow and border strips were 48%, 88% and 98%, respectively (Figure 5).

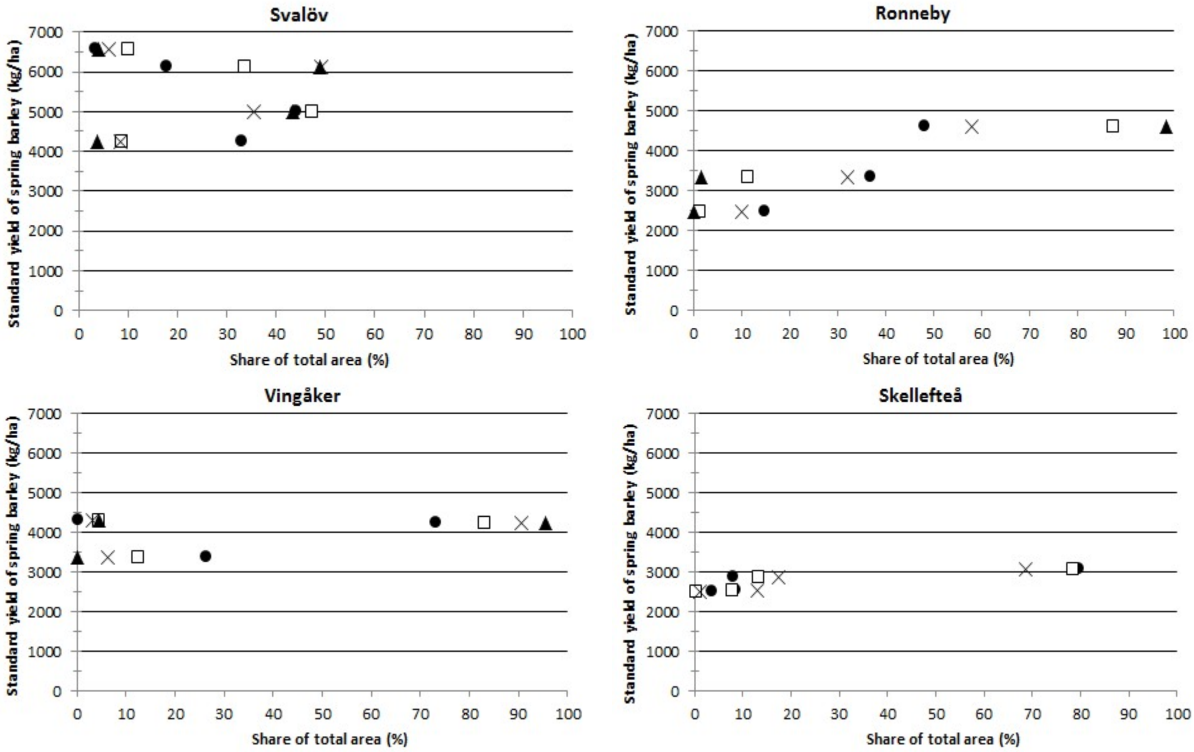

Figure 5. Share of area of low-intensity ley (●), fallow (□), border strips (▲) and all crops (×) for different standard yield area levels in the municipalities investigated. Spring barley was used as a standard yield reference crop

Time demand and costs

The (maximum) driving speed in the passes/rows after calibration ranged from 5.5 km/h to 10.5 km/h (Table 3). When using these speeds (other performance data after calibration are described in greater detail by Nilsson and Rosenqvist (2018)), it was shown that field area and shape had significant impact on the time demand of machine operations (Table 3), especially for small fields. For shape A, for example, the time demand started to increase steeply at about 2 ha. It was also noted that the difference in time demand between 1.50 ha (shape A) and 0.75 ha (shape A) or 1.50 ha (shape B) was about the same. For wide machines with fewer passes, the shape may be important also for larger fields, as the length of idle passes after the work is completed may be time consuming (cf. fertiliser distribution in fields of 6.00 ha and 12.00 ha in Table 3).

Table 3. Driving speed in the pass/row after calibration, and time demand (min/ha) for different machine operations in fields with areas 0.75, 1.50, 3.00, 6.00 and 12.00 ha with shapes A and B (Figure 2).

Operation	Speed km/h	0.75 ha A	0.75 ha B	1.50 ha A	1.50 ha B	3.00 ha A	6.00 ha A	12.0 ha A
Stubble cultivation (4.0 m)	7.0	40.9	43.8	32.8	38.0	29.0	26.7	25.2
Ploughing (2.0 m)	7.5	78.6	100.4	61.8	80.2	54.9	51.0	47.5
Harrowing (8.0 m)	10.5	18.8	23.9	16.3	18.0	13.6	12.0	10.4
Grain drilling (6.0 m)	7.5	36.3	41.7	26.7	34.5	23.3	20.3	19.1
Rolling (12.0 m)	7.5	21.5	23.2	14.5	17.1	12.5	9.9	9.3
Fertiliser distribution (24.0 m)	10.0	13.5	22.6	13.0	19.6	11.4	10.0	10.7
Spraying (24.0 m)	7.0	20.8	26.5	12.2	19.2	11.7	8.6	8.5
Combine harvesting (6.0 m)	5.5	53.6	60.0	39.9	50.5	34.7	30.3	28.1
Mowing (3.0 m)	10.0	42.6	56.8	33.5	44.9	29.1	26.5	24.9
Windrowing (6.0 m)	8.0	26.2	26.4	20.4	25.5	18.2	16.1	15.4
Silage baling (3.0 m)	9.0	48.6	61.2	38.6	50.0	34.5	31.7	30.1

The machinery costs were about 19% higher for spring barley than for ley in fields with an area of 12.00 ha and 28% higher in fields with an area of 0.75 ha (shape A) (Figure 6). Thus, the relative competitiveness of ley increases as the field area decreases. For more irregular fields (shape B), the costs for spring barley were 21% and 22% higher than for ley for the areas 1.5 ha and 0.75 ha, respectively. To keep the costs as low as possible for small and irregular fields, the number of (or intensity of) machine operations should be minimised. This could be done by cultivating perennial crops with low needs of machinery input. In the forthcoming research in this project, the economic profitability of different perennial alternatives such as grasses (see also Nilsson et al. (2015)), *Salix*, poplars and Norway spruce will be evaluated. The influence of cultivation intensity and different payment regimes for environmental benefits (e.g. soil carbon sequestration) will also be analysed.

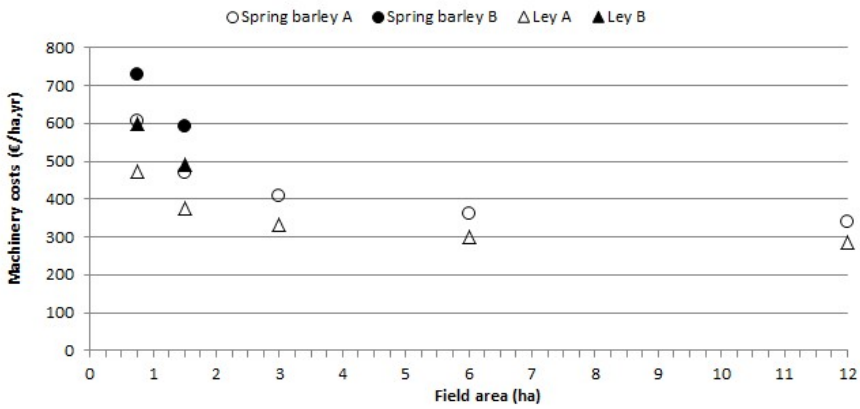

Figure 6. Total machinery costs (€/ha,yr) for cultivation of spring barley and ley in fields with different areas (0.75, 1.50, 3.00, 6.00 and 12.00 ha) and shapes (A and B)

Conclusions

The average parcel area for 'marginal' fields, such as fallow and low-intensity ley culture, was in the range 1-2 ha, which was smaller than for 'normal' fields with e.g. cereal crops. Marginal fields often have a more irregular shape, and they are often more distant, but this was dependent on region and type of landscape. Field area and field shape had significant impact on time demand and costs of machine operations. For example, the time demand and costs rose steeply for fields smaller than about 2 ha as a result of more time, relatively seen, spent on e.g. turnings. Furthermore, the machinery costs of ley increased to a lesser degree, compared to the machinery costs of spring barley, as the field area decreased.

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