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Field characteristics driving farm-scale decision-making on land allocation to primary crops in high latitude conditions

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ABSTRACT

To govern better future landscape planning of high-latitude agricultural systems, it is necessary to understand fully the drivers that currently determine farmers' land allocation to different crops. The aim of this study was to identify key farm and field characteristics that drive farmers' land allocation, based on substantial datasets, and to benchmark findings for farmer perceptions with interviews. Focus was on characteristics that are easily monitored and facilitate development of a field optimization tool to support future implementation and monitoring processes for land use changes at farm and field scales. Drivers for land allocation to different crops varied between crop production and dairy farms, but less evidently between southern and northern regions. Crop choices differed among regions, being greater for southern than for northern farms, but also for farm types, dairy farms mainly cultivating on-farm feed. Some special crops, such as potato and reed canary grass, represented diversified land use in the northern region, but farmers tended to allocate such crops very strictly to certain types of field and did not diversify crop rotations. Interviewed farmers highlighted the complexity of land allocation and the interactive nature of the drivers. When comparing outcomes of the data analyses and farmers' interviews, field size, distance from farm center and soil type were considered to be primary drivers for land allocation. Field shape, slope and land ownership, but only in the case of long-term contract periods, were hidden drivers, identified using statistical analyses, but were not specifically referred to by farmers. Proximity to waterways was the only field characteristic classified as unimportant. Farmers highlighted logistical advantages as an important driver for land allocation, which was confirmed by data analyses. A farmer's justification process for land allocation is likely to be based on intergenerational transitive knowledge and concepts of operationally critical farm and field characteristics. Valuable, empirical information gained during this study needs to be coupled with the development of policy measures to develop effective future policy instruments that are not only practicable, but are easily implemented and cost-effective, while remaining coherent with other policies.

1. Introduction

Finland joined the European Union in 1995 and the Agri-Environment Program (AEP) was launched as a part of the Common Agricultural Policy (CAP), aiming to reduce the environmental footprint of high-latitude agriculture. Together with the economic challenges experienced by farmers due to substantial changes in markets and prices, this resulted in numerous changes to input use and crop management (Peltonen-Sainio et al., 2015a). In spite of being successful in reducing agricultural nutrient balances (Salo et al., 2007), yield stagnation and quality deterioration were evident for virtually all major and minor crops (Peltonen-Sainio et al., 2015a; Peltonen-Sainio et al., 2016).

Because Finland has vulnerable environments and abundant fresh-water resources (Peltonen-Sainio et al., 2015b) and has recorded large yield gaps (Boogard et al., 2013; Peltonen-Sainio et al., 2015a; Peltonen-Sainio et al., 2016), sustainable intensification has potential for high-latitude agriculture and could combine improvements in productivity and competitiveness with environmental benefits in a socially acceptable manner. Sustainable intensification emphasizes land use planning based on assessment of yield gaps on field, farm and regional scales (Bommarco et al., 2013), complemented by information on the primary properties of the field parcels that impact functionality of field operations.

Diversification of crop rotations and agricultural landscapes is targeted to provide ecosystem services: to maintain soil quality, functions and carbon stores, to benefit from improved nutrient cycling and to alleviate crop protection risks and need for pesticides (Kirkegaard et al.,

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2008; Potts et al., 2010; Wezel et al., 2014; Nemecek et al., 2015). Therefore, diversification of agricultural landscapes is a core component of sustainable intensification (Soussana et al., 2012; Bommarco et al., 2013). In the case of Finland having highly variable field conditions and large yield gaps, sustainable intensification would mean allocation of agricultural land to: a) highly productive, input-responsive fields that are sustainably intensified, b) unproductive fields with deficiencies, possibly caused by monoculture and adverse changes in crop management, which are allocated to extensification and greening, to provide ecosystem services and stimulate recovery from key deficits, and c) afforested fields making no current or future contribution to food security for various critical shortcomings. By this means, instead of delivering nutrients evenly to all fields, farmers might focus their inputs, energy, time and other resources on the most productive, input-responsive fields.

In addition to large yield gaps, important as a part of the demarcation process between land sharing and land sparing, successful launching of sustainable intensification is critical for climate-smart agriculture at high latitudes. One can envisage marked future land use changes occurring due to climate warming as a means to address the challenges, but also benefit from the opportunities of a longer growing season for high latitude agriculture (Peltonen-Sainio et al., 2009; Olesen et al., 2011). Climate change is progressing rapidly at high latitudes (IPCC, 2013), which calls for proactive land use planning because longer growing, later maturing crops could potentially be introduced into more northern regions and many novel crops might be introduced into cultivation to diversify crop rotations further (Olesen et al., 2011; Elsgaard et al., 2012). Future options for diversification of land use through crop choice will be essential to improve resilience to climate variability and extreme weather events (Reidsma et al., 2010), projected to be more frequent in the future (IPCC, 2012). As comprehensive land use changes may take place at high latitudes in the coming decades (Olesen et al., 2011; Elsgaard et al., 2012), effective policy instruments are needed to govern the change that might otherwise be spontaneous and not target or achieve desired changes in agriculture through environmental sustainability, economic profitability and social acceptability that could become reality through future land use changes. However, the current knowledge gap on field scale production capacities and numerous parcel characteristics that determine efficiency of farming operations, precludes comprehensive landscape planning, the key step towards sustainably intensified agricultural systems.

To govern the future landscape planning better, thorough understanding is needed of the drivers that currently influence farmers' land allocation to different crops, thereby impacting planning of crop rotations (Peltonen-Sainio et al., 2017). Such understanding is essential to develop coherent policy instruments that are socially acceptable and target economic and environmental sustainability, but which can also be implemented by farmers and encourage progress with well-targeted, large-scale land use planning. This requires continuous focus on addressing controversies associated with developing sustainably intensified, climate-smart agricultural systems (Steenwerth et al., 2014). The aim of this study was 1) to identify farm and field characteristics that are key drivers for farmer's land allocation based on substantial datasets, 2) to benchmark findings for farmer perceptions with interviews, 3) focus on characteristics that are readily monitored and to facilitate development of a field optimization tool to support future implementation and monitoring processes for land use changes at farm and field scale.

2. Materials and methods

Data from the Agency of Rural Affairs (Mavi) from 2011 to 2014 were used to assess the allocation of field parcels to different crops and crop groups typical for each study region. The data were for 64,744 fields representing crop production farms and 9274 representing dairy farms in the prime southern agricultural region of Finland (N: 60° 40′ − 61° 24′; E: 22° 08′ − 23° 20′) as well as 27,855 and 30,799, respectively, from the northern dairy production region (Ruukki region, N: 63° 48′ − 66° 00′; E: 24° 09′ − 27° 00′; Maaninka region, N: 62° 49′ − 63° 48′; E: 26° 00′ − 28° 37′). These corresponded to a total land area of 203,000 ha and 24,600 ha for the southern region and 68,200 ha and 69,200 ha for the northern region, respectively. Finland has approximately 2.2 million ha of agricultural land.

The total field area of farm and the following seven characteristics of each field parcel were gathered from different official sources (if not otherwise specified, data originate from Mavi):

1) Size: < 0.5 ha, 0.5–0.99 ha, 1.0–2.99 ha, 3.0–4.99 ha and ≥5.0 ha
2) Distance from the farm center: < 300 m, 300–599 m, 600–1199 m, 1200–2499 m, 2500–4999 m and ≥5000 m. Farm center was characterized as a mid-point of the median field. The median field was a field that minimized the average Euclidean distance between the field and other fields of the farm.
3) Shape: < 0.3, 0.3–0.49, 0.5–0.69 and ≥0.7. Shape was measured as the square root of area of field divided by the length of its boundaries divided by four; i.e., shape is 1.00 for a completely square field.
4) Slope (%): < 1.3%, 1.3–2.89%, 2.9–6.99% and ≥7.0%, i.e., average soil surface slope of the field, calculated in a 25 × 25 m grid from the laser scanning data produced by NLS National Land Survey of Finland.
5) Proximity to waterway: next to any waterway (lake, river or main ditch), < 50 m, 50–99 m, 100–299 m and ≥300 m to a waterway (see Peltonen-Sainio et al., 2015b).
6) Dominant soil type according to Lilja et al. (2006): coarse mineral soils like *Haplic Podzol 1* and *2*, clay soils like *Vertic Cambisol* (Clay 1, not in northern region), clay soils like *Eutric Cambisol, Gleyic Cambisol* and *Gleysols* (Clay 2), and organic soils like *Fibric/Terric Histosol 1* and *2* and *Dystric Gleysol*.
7) Ownership: owned by the farmer or leased.

Only field parcels of > 0.3 ha and including either a single prime crop or having a dominant crop with ≥70% of field area were included in the analyses. This is because if the field parcel contained many agricultural parcels (see e.g. Peltonen-Sainio et al., 2015b), the information on layout of different crops within a field parcel was missing.

Different crop alternatives were available depending on region (south/north) and farm type (crop/dairy). The following crops were available at sufficient frequency to allow statistical analyses (grouped in the case of similar outcome):

1) For the southern crop production farms: spring wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.), spring rapeseed [turnip rape (*Brassica rapa* L.) and oilseed rape (*B. napus* L.)], winter cereals [wheat and rye (*Secale cereal* L.), pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.), sugar beet (*Beta vulgaris* var. *altissima*), perennial grasslands, non-productive green fallows (e.g. nature managed fields, fallows), and a group of the rest (i.e., minor crops that were statistically too irregular to enable analyses on a crop basis) containing primarily green manuring grasslands, caraway (*Carum carvi* L.), starch potato (*Solanum tuberosum* L.) and some horticultural crops.
2) For the northern crop production farms: spring barley and oat, spring turnip rape, potato, perennial grasslands, non-productive green fallows, and the rest containing green manuring grasslands, reed canary grass (*Phalaris arundinacea* L.) and caraway.
3) For the southern dairy farms: spring wheat, other spring cereals (barley and oat), perennial grasslands, non-productive green fallows, and the rest containing pastures, winter wheat and cereal mixtures.
4) For the northern dairy farms: spring cereals (barley and oat),