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Research Paper

Phosphorus redistribution by dairy cattle on a heterogeneous subalpine pasture, quantified using GPS tracking

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A B S T R A C T

Traditional summer pastures in the Alps have been shaped by centuries of grazing by domestic livestock. To understand the effects of this land use on nutrient cycling, we quantified phosphorus (P) fluxes on a summer farm in southeastern Switzerland. We used high-frequency GPS tracking to record the spatial distribution of animal activities over an entire grazing season, and used these data to model spatial patterns of P depletion and accumulation at various spatial scales (the entire farm, four vegetation groups, 900 m^2 sampling plots and 10×10 m^2 grid cells). Since the model depended on parameter values obtained from diverse sources, we tested its robustness using Monte Carlo simulations based upon varying parameter values. The model indicated very small net P fluxes (between − 0.05 and + 0.05 kg P ha^{-1} yr^{-1}) over nearly half (49%) of the pasture, mostly in dwarf-shrub vegetation. In a further 44% of the area, P depletion exceeded -0.05 kg P ha^{-1} yr^{-1}, representing a total loss of 39.4 kg P yr^{-1} (2.1 kg P ha^{-1}). A positive P balance of over 0.05 kg P ha^{-1} yr^{-1} was indicated for 6.6% of the area, representing a total annual accumulation of 16.4 kg P (1.8 kg P ha^{-1}). The overall P balance for the entire summer farm was thus negative. The patches of substantial depletion or accumulation formed a mosaic in the areas most used by cattle. More active management of cattle and stable manure is recommended to maintain the delivery of ecosystem services.

1. Introduction

Large herbivores can greatly affect the productivity and botanical composition of pastures (Olff and Ritchie, 1998; Jewell et al., 2005). Besides direct effects through selective grazing and trampling, they also affect the vegetation indirectly by taking up nutrients in their food and returning them as dung and urine (Haynes and Williams, 1993). The spatial use of pastures by grazing animals is affected by factors such as topography, the quality of vegetation and the distance from water sources (Homburger et al., 2015), so that nutrients are rarely returned uniformly. Areas with good quality vegetation are preferred for grazing, while flat, sheltered areas are selected for ruminating and resting. At a smaller spatial scale, patches close to dung are avoided by grazing animals (Gillet et al., 2010). These contrasting patterns of grazing and excretion cause a spatial re-distribution of nutrients within the pasture, producing local areas of depletion or accumulation (Edwards and Hollis, 1982; Jewell et al., 2007).

Summer pastures in the Swiss Alps, which account for one third of Switzerland's agricultural land (Baur et al., 2007), are grazed during the summer months by cattle, goats or sheep. Through centuries of traditional low-intensity management, they have developed into ecosystems of high cultural value and biodiversity (Lauber et al., 2014). Today, however, they are threatened by two contrasting trends: intensification of the more easily accessible and productive pastures, and neglect of the more isolated and less productive areas (Baur et al., 2007). Both processes can cause pasture degradation and a decline in biodiversity, and may lead eventually to the pasture being abandoned (Tasser and Tappeiner, 2002).

Against this background, it is important to understand how management affects the quality and productivity of subalpine pastures. Several studies have shown how heterogeneities in pasture use by cattle lead to a spatial redistribution of nutrients, which in the long term may have profound consequences for soil conditions and vegetation (Kohler et al., 2006; Auerswald et al., 2009; Schnyder et al., 2010). Quantifying this process of nutrient transfer has proved difficult, however, with most studies relying upon indirect methods to infer patterns of uptake and excretion. In their study of P redistribution on a large subalpine pasture area in southern Switzerland, Jewell et al. (2007) inferred patterns of habitat use by visually observing the distribution and activities of animals at hourly intervals. However, this method provided

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an incomplete picture of habitat use, and only during daylight hours.

In this study, conducted on a summer farm of 135 ha in the Swiss Alps, we followed the approach of Jewell et al. (2007), but used GPS tracking to obtain more detailed information on habitat use by cattle during a complete grazing season. The GPS technique has the advantage that animals can be tracked continuously and with greater spatial precision than is possible by direct observation (Homburger et al., 2015) – and the data can also be used to determine the main types of animal activity (Homburger et al., 2014). Based upon these data, we estimated the flows of phosphorus within and off the pasture. Phosphorus (P) is an important and, together with nitrogen (N), often a limiting nutrient in these ecosystems and can have strong effects on the vegetation (Vitousek et al., 2010). However, the fluxes of P in a grazing ecosystem are easier to study than those of N, due to fewer transformation processes in ruminants, including no symbiotic fixation and no gaseous losses. In addition, measuring the P in dung provides a good estimate for nutrient return to the soil, because P concentrations in the urine of cattle are usually negligible (Karn, 2001). Furthermore, because of symbiotic N fixation, P availability might have a greater effect on plant species composition than N enrichment (Wassen et al., 2005).

The pasture we studied was grazed by dairy cattle, which differ from beef cattle in their effects on nutrient turnover. First, a significant proportion of the nutrients ingested by dairy cattle are exported in the form of milk, and therefore lost from the system. Second, because dairy cows are milked twice a day, they return regularly to the stable building, thereby reducing the use of more remote areas and making stable manure available for the strategic redistribution on productive pastures.

The objectives of the work described here were to i) quantify P fluxes by dairy cattle on a subalpine pasture, ii) develop a spatially explicit flux model with which to map areas of P depletion and P accumulation within the pasture; iii) relate spatial patterns of P balance to quantities of P in the soil, and iv) determine the P budget for the entire grazing area under the present form of dairy production.

2. Methods

2.1. Study site

The study site was Alp Sura, a summer farm near the village of Guarda (46°46′33″N/10°08′59″E) in the Canton of Grisons in south-eastern Switzerland. The pasture is situated at an elevation between 2000 and 2400 m a.s.l. and has a south-westerly to westerly aspect (Fig. 1). Soils are lithic leptosols and weakly developed cambisols, frequently less than 30 cm deep with a pH (H_2O) between 4.8 and 5.3. The underlying parent material is crystalline and dominated by amphibolitic rocks (Cadisch et al., 1941). The mean annual precipitation derived from gridded data of MeteoSwiss, Zurich was 1206 mm yr^{-1}. Mean annual temperature was 0.3 °C (Hiebl et al., 2009).

We mapped the vegetation at the level of the phytosociological alliance following Delarze and Gonseth (2008), using a minimal unit of 400 m^2. The alliances were reclassified into four vegetation groups (Fig. 1):

Group 1 are fertile pastures dominated by broad-leaved grasses and herbs associated with more nutrient-rich conditions, such as *Phleum rhaeticum* (Humphries) Rauschert, *Poa alpina* L., *Deschampsia cespitosa* (L.) P. Beauv. and *Alchemilla vulgaris* aggr.

Group 2 are forb-rich pastures dominated by *Crepis aurea* (L.) Cass., accompanied by grasses such as *Festuca rubra* L. and *Agrostis capillaris* L.

Group 3 are nutrient-poor pastures dominated by the fine-leaved grasses *Nardus stricta* L. and *Avenella flexuosa* (L.) Drejer and only very few forbs, in lower areas with scattered *Larix decidua* Mill. trees.

Group 4 are dwarf-shrub pastures with high proportions of *Juniperus communis* subsp. *nana* Syme, *Rhododendron ferrugineum* L. or *Vaccinium* spp.

2.2. Livestock management and activity monitoring

The study site has been used for dairy cattle for many centuries, though detailed historical information is sparse. Over 100 animals used to graze on this and neighbouring pastures in the 1970's (Werthemann and Imboden, 1982), but since then the area was confined and numbers have declined, and in recent years have fluctuated around 50. During 2011, when our fieldwork was conducted, there were initially 47 cows on the pasture, but this number was reduced as dry cows were successively moved to a more distant pasture (Fig. 2a).

Because of the short growing season, the summering period on Alp Sura is usually only about 70 days, from the end of June to the end of August. During the remaining time, no agricultural use is possible and the animals are kept at the principal farm in the valley, at around 1400–1600 m a.s.l.. Cows are free to roam more distant parts of the pasture during the day, but are moved to smaller paddocks located near the main building at night (Fig. 1). The animals are milked twice a day, at between 6 and 8 am, and 5 and 7 pm.

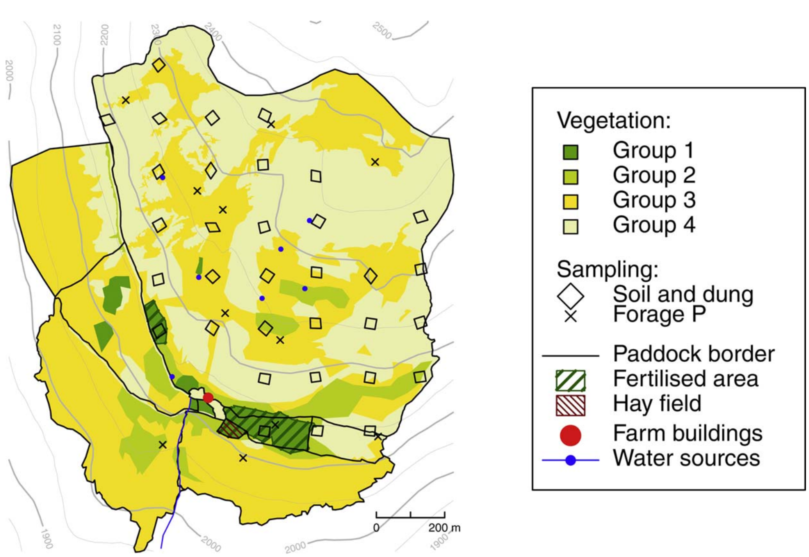

Fig. 1. Map of the study site indicating the distribution of vegetation groups, sampling locations, water sources and paddock borders. The four vegetation groups are indicated by colors. Crosses and rhombi are showing the sampling locations for forage (1.2 × 1.2 m^2) and soil as well as dung (30 × 30 m^2). Areas receiving farmyard manure are shaded in green, those cut for emergency roughage in red. Further, the location of the farm buildings and water sources are shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)