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# Spatial variability of potassium in agricultural soils of the canton of Fribourg, Switzerland

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ABSTRACT

Potassium (K) is a crucial element for plant nutrition and its availability and spatial distribution in agricultural soils is influenced by many agro-environmental factors. In Switzerland, a soil monitoring network (FRIBO) was established in 1987 with 250 sites distributed over the whole of the canton of Fribourg (representing 4% of the surface area of Switzerland), whose territory is shared between the Swiss Midlands and the Western Alp foothills. In this study area, diverse geological deposits (sandstone, marlstone, silts and calcareous rocks), soil types (Cambisols, Gleysols, Rendzinas, Luvisols and Fluvisols) and land uses (cropland, permanent grassland and mountain pasture) are present, making the network interesting for assessing the relative contribution of environmental variables and land use management on soil properties. The aims of the present study were to (i) characterize the soil K status in the Fribourg canton according to four different extraction methods; (ii) analyse the spatial variability of soil K in relation to land use, soil type, soil parent material and topography; (iii) evaluate the spatial predictability of K at the canton level; and (iv) analyse the implications for K fertilization management. The overall amount of soil total K averaged 13.6 $g \cdot kg^{-1}$ with significant variations across the sites (5.1–22.1 $g \cdot kg^{-1}$). The spatial distribution of total K content was influenced by relatively extended soil forming processes, as suggested by (i) a significant global spatial autocorrelation measure at the 10 km scale (Moran's $I = 0.43$); (ii) significant differences observed among soil types and soil parent materials and (iii) significant correlations with land attributes such as elevation ($r = -0.51$). On the other hand, available mean K forms were significantly different among land uses, with the highest mean values of available K encountered in permanent grasslands, from 46.3 $mg \cdot kg^{-1}$ (water extraction) to 198 $mg \cdot kg^{-1}$ (acetate ammonium + EDTA extraction). All K forms (total and available) showed similar spatial regional patterns for all spatial interpolation methods, with areas dominated by permanent grassland and crops presenting higher values. However, these trends were less pronounced for the available K forms due to the prevalence of on-farm management practices for these K forms (*e.g.* fertilization), likely inducing high spatial and temporal variability. This hypothesis was supported by spatial clustering of low and/or high K fertility status that could be related to local particular farming practices. Grasslands require particular attention with regard to overall high K fertility status.



## 1. Introduction

Potassium (K) is a crucial element of plant nutrition and is the second largest nutrient assimilated by plants after nitrogen (Marschner, 2012). It is generally abundant in soil as it constitutes about 2% of the earth's crust (Schroeder, 1978). Not all of its forms, however, are readily available to plants. It is generally recognized that soil K occurs in soil in four forms: water-soluble, exchangeable, non-exchangeable and structural (Sparks, 1987; Syers, 2003). Among these different forms, dynamic equilibrium reactions control the release and/or fixation of K according to soil biogeochemical properties and processes (Zörb et al., 2014). Therefore, distribution of soil K forms is influenced by many agro-environmental factors, such as soil parent materials (Askegaard et al., 2004; McLean and Watson, 1985; Öborn et al., 2005), degree of soil weathering (Andrist-Rangel et al., 2006; Barré et al., 2008; Johnston and Goulding, 1990), topography (Kozar et al., 2002; Winzeler et al., 2008) and nutrient balance (Bertsch and Thomas, 1985; Simonsson

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et al., 2007). Despite the natural abundance of K in soils (Askegaard et al., 2004; Schroeder, 1978), certain regions of the world, such as Australia, China and Iran, present crop K deficiencies over large areas due to particular pedoclimatic conditions or long-term under-fertilization of K (Brennan and Bell, 2013; Hseung, 1980; Ji-yun, 1997; Malakouti, 1999; Römheld and Kirkby, 2010). In Europe, soil K deficiencies are not widespread (Tóth et al., 2013), but deficiencies or reduction of soil K are reported at the regional scale, especially in countries around the Baltic Sea and in the United Kingdom (Andrist-Rangel et al., 2010; Tóth et al., 2013). In Switzerland, there has been no study on soil K status on a national scale, as K deficiencies in crops are scarce and only reported at the plot scale. However, there are increasing concerns about the quality of fodder as a consequence of potential K over-fertilization (Kessler, 1997).

Understanding soil K status is important when developing appropriate K nutrient management. Potassium fertilization strategies and recommendations essentially rely on soil analyses using different extraction methods to assess its availability with respect to plant uptake and crop production. Nevertheless, the complex behavior of K in soil hinders assessment of K plant availability as each K form contributes to plant nutrition at different levels (Zörb et al., 2014). Current K fertilization recommendations are based on the amount of water-soluble ($K_W$) or exchangeable K ($K_{AAE}$) (Sinaj et al., 2009; Mallarino et al., 2003), as these forms are considered readily available (Syers, 2003). The assessment of soil K availability by means of current soil tests is still under discussion as the K plant uptake could be limited under particular conditions (Blake et al., 1999; Franzen and Peck, 1997; Khan et al., 2014). There is evidence that other K forms (*i.e.* non-exchangeable and structural K) may contribute significantly to plant nutrition (Bertsch and Thomas, 1985; Blake et al., 1999; Chatterjee et al., 2015; Jalali, 2007), especially when exchangeable K content is low (Schneider, 1997). Therefore, the evaluation of soil K fertility should take into consideration all different K forms (Chatterjee et al., 2015).

The recent availability of geo-referenced soil databases offers opportunities to improve the prediction of the spatial distribution of nutrients. Spatial investigation of soil nutrient fertility relies on geostatistical methods, which allow the continuous prediction of soil properties from a network of sampling points (Webster and Oliver, 2007). One of the most accepted and widely used method integrating auxiliary variables, for example elevation-derived terrain attributes and remote sensing data, is regression kriging (RK) (Hengl et al., 2004; McBratney et al., 2000; Odeh et al., 1994, 1995). Such method is capable of handling complex and extensive data by systematically and statistically analyzing patterns in the measured values (Breiman, 2001). However, generated patterns *via* interpolation techniques need to be validated independently and evaluated by experts with knowledge about the study area, in order to discriminate between patterns that result from purely statistical computations and patterns that are supported by natural processes or management induced.

Agriculture in the Fribourg canton is an important activity shaping the landscape and affecting the environment. In this context, K is an important nutrient for local agricultural activities such as dairy production in the alpine region and cash crop production in the plains (*e.g.* potatoes and sugar beets). In Switzerland, fertilization guidelines rely on the status of water-soluble and exchangeable K (Sinaj et al., 2009). An analysis of nutrient balance on a national scale established by Spiess (2011) suggests a current surplus of K in soil due to farming activities. However, no regional investigation of the different K forms has been yet conducted. The establishment of the FRIBO network since 1987, by the Agricultural Institute of the Fribourg canton for surveying soil quality (Rossier et al., 2012) provides an opportunity for conducting regional studies. The objectives of this study were to (i) characterize the soil K status in the Fribourg canton according to four different extraction methods; (ii) analyse the spatial variability of soil K in relation to land use, soil type, soil parent material and topography; (iii) evaluate the spatial predictability of K at the canton level; and (iv) analyse the implications for K fertilization management.

## 2. Material and methods

### *2.1. Study area*

The Fribourg canton (1670 km$^2$, *i.e.* 4% of Switzerland) is located in the western part of Switzerland (46°4′N; 7°5′E). It presents diversified landscapes as it is located at the interface between the Swiss Midlands (northwest part of the canton) and the Western Alps foothills (southeast part of the canton). The topography is characterized by gentle slopes on the northwest that gradually lead to steep slopes towards Westerns Alps foothills. According to the meteorological data (Meteosuisse IDAweb database, available at http://www.meteosuisse.admin.ch/), local climate is temperate continental with cold winters (lowest mean monthly temperature observed in January: −3.1 °C) and mild summers (highest mean monthly temperature observed in July: 17.6 °C). The mean annual temperature reaches 8 °C. On average, annual precipitation amounts to 1118 mm and monthly values range from 63 mm (February) to 129 mm (August). However, climatic conditions are not homogeneous across the study area, notably due to the topography, especially elevation. In the hilly and mountainous part (SE), conditions are generally colder and wetter. Similar to the climate, geological formations and soil types present a NW-SE gradient through the canton and are related to topography (Fig. 1). Regional geology is complex as a result of quaternary glaciation, glacier deposits and subsequent fluvial erosion (Signer et al., 2000) (Fig. 1a). The north-central part of the study area is characterized by low molasses-type hills covered by moraine deposits, whereas the southern part encompasses flysch regions and alpine regions on calcareous formations. Based on soil parent material, major soil types are Cambisols in the north-central part of the study area and a composite of Regosols, Gleysols, Rendzinas and Lithosols (Fig. 1b). Locally, other soil types such as Luvisols and Fluvisols are also present.

The FRIBO network was established in 1987 by the Agricultural Institute of the Fribourg canton and aims at monitoring pedological and agro-environmental conditions across the canton (Rossier et al., 2012). This network includes 250 sampling sites evenly distributed along an approximate 2 ∗ 2 km grid. Since 1987, approximately 50 sites have been sampled each year. Thus, every 5 years, all the sites have been sampled within a “cycle”. In the present study, the FRIBO data collection of the 5th cycle (2007–2011) was used. Five out of the 250 sites were removed from our analyses due to extreme soil organic matter (SOM) content, which induced outliers in the different measured K forms.

Among the 245 sampling sites of the 5th cycle, three different land uses are represented: 121 sites in croplands, 80 in permanent grasslands and 44 in mountain pastures (Fig. 1). Croplands were mostly cultivated according to a meadow-maize-wheat-barley-rapeseed rotation, but some sites included other crops such as tubers, vegetables, orchards and vineyards. Permanent grasslands encompassed meadows that have been established for at least 6 consecutive years. Mountain pastures relate to specific grasslands, were located in the steep areas of the alpine part of the canton and were mostly grazed during summer. The spatial distribution of land uses also followed a NW-SE gradient, similar to soil types and terrain characteristics (Fig. 1). On each site, management of K fertilization was performed according to the Swiss fertilization guidelines for crops and grassland (Sinaj et al., 2009), generally with chemical fertilizer (potassium chloride) in croplands and cattle manure in grasslands and mountain pastures.

### *2.2. Soil sampling and analysis*

At each site, composite soil samples of the surface horizon (0–20 cm for croplands and 0-10 cm for grasslands and mountain pastures) were derived from 25 soil cores sampled over an area of 100 m$^2$. The 245 sites