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Trends in soil–land-use relationships in the Netherlands between 1900 and 1990

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ABSTRACT

The distribution of agricultural land use today is less dependent on soil properties than in the past, as a result of technological advances. This fact has long been suspected by scientists from different disciplines, but the changing relationships between specific soil types and specific forms of land use have so far not been tested quantitatively. In this paper, we have quantified the association between soil type and land use for the Netherlands, for the years 1900, 1960, 1980 and 1990. For our analyses, we distinguished 21 soil groups and four land use classes. Cramer's *V* was used as a statistical measure to quantify the association.

As a general trend, we find that associations are indeed weakening: intrinsically poor sandy soils became increasingly cultivated, while intrinsically rich soils are no longer reserved exclusively for crop cultivation. This general trend does not apply to all soil types, however: drift sands and other coarse sandy soils where large-scale mechanization was impeded by an undulating topography remained uncultivated. Moreover, even though the trend of a decrease in association is very clear we have several reasons to think that it may not decrease further in future. One reason is that inputs such as fertilizers which influenced the trend over the period 1900–1990, are nowadays less used than two decades ago as a result of environmental policies. Other reasons are the growing support for geoheritage and biodiversity.

1. Introduction

Historically, land-use decisions were strongly influenced by the limitations and possibilities of the underlying soils. Soils are the matrix for roots, a reservoir of organic carbon and water, and a source of nutrients (Larney et al., 2000). Poor soils fail in performing one or more of these functions, which limits the possibilities for agricultural use. In addition, some soil properties, such as high clay content or stoniness, constrain important cultivation activities such as ploughing (Godwin and Spoor, 1977). For growing crops, farmers selected soils that were deep, fertile, and had a favourable texture, both for holding water and for ploughing and harvesting operations. The more difficult soils, i.e. soils too wet, too shallow, or otherwise too poor for crop cultivation, were mostly used for pasture. Soils that were unsuitable even for that purpose (e.g. dry sandy soils or peat bogs) were left under natural vegetation, and were at most extensively used for rough grazing, wild food collection, or wood extraction. As a result of the different constraints for the various types of land use, the spatial distribution of soil types can often be recognized in land-use patterns (Abler et al., 1971; Grigg, 1984). These patterns have been referred to as 'traditional' landscapes (Antrop, 1997), although that term may wrongly create the impression that these landscapes were unchanging. We may also speak of landscape coherence, which is the similarity between soil patterns and land use (Mander et al., 2010).

In time, however, technological development has made it easier to overcome soil-related constraints (Yaalon and Arnold, 2000). For example, artificial fertilizers were introduced, drainage and irrigation technology became cheaper and more advanced, and cultivars were developed which were more resistant to drought and diseases (Tilman et al., 2002). Especially for crop cultivators, such developments opened up wide areas which had previously been considered unsuitable for cultivation. At the same time, however, pressure on land resources grew and competition with other land uses (industries, urbanization, infrastructure) increased. With increasing demand for animal products, dairying in particular became more profitable. As land tends to be used for that purpose which brings greatest benefits to its owner, soils traditionally reserved for crop cultivation became increasingly used for dairying, which is usually the most intensive form of pasture use. Crop cultivation was forced to move to less favourable soils or to areas further from markets. In this way, the dynamic interaction between natural and

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cultural forces in the environment has changed rural landscapes (Antrop, 2005).

We hypothesize that these developments, which have particularly taken place in industrialized countries, have caused structural changes in the relationship between soils and land use. On the one hand, the relationship may have weakened because of technological progress overcoming inherent constraints. On the other hand, the relationship may have changed as the competitive order of land uses changed i.e. one type of land use became more profitable relative to another one. Associations between land use and soils can have important environmental consequences, as particular associations amplify or mitigate processes such as carbon emissions and sequestration, groundwater pollution, and soil degradation. Moreover, a loss in association results in the loss of landscape coherence, also referred to as geoheritage: historical associations between soils and land use which provide valuable information about the evolution of the landscapes (van der Valk, 2013).

In this paper we explore how the relationship between soils and land use has changed in the Netherlands for the period 1900–1990. We overlay four land-use maps of 1900, 1960, 1980 and 1990 with one soil map, and analyze the development in soil and land-use associations. Our quantitative analysis is followed by a more in-depth qualitative analysis of how a selection of such associations has evolved.

2. Data and methods

2.1. Data

A time series of land-cover maps of the Netherlands was used which was created by (Knol et al., 2004) from historical topographic maps. These maps, reflecting the land cover in 1900, 1960, and 1990 are shown in Fig. 1 (for reasons of space we do not show 1980). The maps are all made in the same way and hence suitable for trend analyses. The original land-cover classes were aggregated to four land-use classes: built-up (original cover-class *built-up areas and roads*), crop cultivation (original cover-classes *arable land* and *greenhouses*), pasture (original cover-class *grassland*), and unused (original cover-classes *forest*, *heathlands and peat*, *marshlands*, and *drift sand*), hereafter referred to as nature. The resolution of the 1960, 1980 and 1990 land-cover datasets was 25 m × 25 m; that of the 1900 land-cover map and the soil map was 50 m × 50 m.

With respect to soil data, we used the PAWN (Policy Analysis for the Water management of the Netherlands) schematization of the 1:250,000 soil map (Hartemink and Sonneveld, 2013; Steur, 1985) resulting in a total of 23 soil functional groups (De Vries, 2008) (Fig. 1). They are referred to as soil functional groups since they are defined using hydro-pedological class pedotransfer functions (Wösten, 1997). In our study, 21 soil groups were used and two classes (urban and water) were omitted.

2.2. Methods

A database was extracted from the maps, by systematically sampling according to a 250 m grid from all land-use maps and the soil map. Furthermore, only observations that were complete for all maps were kept. This resulted in removing the land-use and soil observations of the land reclaimed from the IJsselmeer and parts of the marine districts, since that land did not exist in 1900. In total, the dataset contained 584,687 observations, roughly representing the 34,000 km^2 of the Netherlands minus the reclaimed areas.

For each year (1900, 1960, 1980, and 1990) associations between soil types and land uses were identified by computing Chi-square and Cramer's *V*. Chi-square is used to test the significance of the relationship between two nominal variables; Cramer's *V* is a measure which rescales Chi-square so that it can be interpreted as "the fraction of variable a explained or described by variable *b*", which is equivalent to R^2 for relationships between ratio variables (Cramer, 1999). Chi-square is obtained from contingency tables of, on the one hand, the observed distribution of land use over soil types and, on the other hand, the expected distribution *should land use be randomly distributed over soil types*. The contingency tables contain k rows and l columns, where k is the number of land-use categories and l is the number of soil types. The numbers in the 'observed' contingency table are the numbers of observations of each particular combination i, j of land use i and soil type j. This table is completed by calculating the 'row totals' ($\sum_{i=1}^{k} obs_j$), the 'column totals' ($\sum_{j=1}^{l} obs_{ij}$), and the 'grand total' ($\sum_{i=1}^{k}\sum_{j=1}^{l} obs_{ij}$). The 'expected when random' contingency table is then filled by computing:

$$rand_{ij} = \frac{\sum_{i=1}^{k} obs_j \times \sum_{j}^{l} obs_i}{\sum_{i=1}^{k}\sum_{j=1}^{l} obs_{ij}} \quad (1)$$

The overall association is expressed as a Chi-square measure. It is obtained by:

$$\chi^2 = \sum \frac{(obs_{ij} - rand_{ij})^2}{rand_{ij}} \quad (2)$$

The formula for Cramer's *V* is:

$$V = \sqrt{\frac{\chi^2}{n\ \min(r-1,\ c-1)}} \quad (3)$$

where n is the number of observations, r is the number of rows in the contingency table, and c the number of columns.

The Cramer's *V* values thus obtained were plotted against time so as to explore the development of the soil–land-use association over time. A linear regression line was fitted through the four observations to obtain the average annual rate of change (the regression coefficient) and an indication of the consistency of the change (the R^2).

Next, in order to gain more insight in the development in individual soil–land-use associations, graphs were made that show the development of the land-use percentages on each soil type. This is illustrated in Fig. 2 for three theoretical trajectories. The dashed lines show the percentage of the Netherlands occupied by soil type X, which we suppose is 10% in this example. As soil types are not considered to change in the studied period, nor is the total area of the Netherlands, this percentage is constant in time. The other lines show the development of the percentages of the different land uses on this soil. The advantage of this representation is that the shown trends are irrespective of the overall trends in the land-use areas. Should there be no particular preference of the land uses for soil type X or any other soil type, all land uses would have approximately 10% of their total area on soil type X. However, in this example, crop cultivation is overrepresented on soil type X, while pasture is underrepresented. This either indicates a particular preference of crop cultivators for soil type X, or a particular aversion of livestock farmers to that soil type. In graph 2a this association grows weaker over time, while in graph 2b this association grows stronger over time. In general, a convergence to the dashed line indicates a weakening association between land use and soil type, while a divergence from the dashed line indicates a growing association between land use and soil type. In graph 2c the land-use lines cross the dashed line, indicating a structural change in the relationship between land use and soil type. Such a trend indicates that the relationship between land use and soil is not necessarily weakening, but rather that a new land-use configuration is emerging.