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Abstract

Background

Child mortality differed greatly within rural regions in Europe before and during the mortality decline. Not much is known about the role of nutrition in such geographic differences, and about the factors affecting the nutritional level and hence the resistance to diseases.

Objective

Focusing on nutrition, we analyse the effects of soil type, used as an indicator of the farm-level agricultural productivity and hence of nutritional status, on mortality of children aged 1-15 living in five rural parishes in southern Sweden, 1850-1914.

Methods

Using longitudinal demographic data combined with unique geographic micro-data on residential histories, the effect of soil type on the mortality risks are analysed considering as outcome all-cause mortality and mortality from non-airborne and airborne infectious diseases.

Results

Soil type primarily affected the mortality of farmers' children, but not labourers' children. Particularly, farmers' children residing in areas with very high proportions of clayey till (75-100% coverage) experienced lower risks of dying compared to children residing in areas with other soil types such as clay and sandy soils.

Conclusions

Certain soil types seem to have influenced the agricultural productivity, which, in turn, affected the nutrition of the farmers' children and thus their likelihood of dying. The results indicate a relatively important role of nutrition as a mortality predictor for these children.

Contribution

As, to our knowledge, the first longitudinal study on the micro-level that analyses the effects of soil type on mortality in a historical rural society, we contribute to the literature on the role of nutrition on the risk of dying in a pre-industrial society.

Acknowledgement

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Keywords: child mortality, geographic context variables, GIS, historical demography, soil quality, southern Sweden

JEL codes: J10, N5, N9

1. Introduction

This paper studies the role of nutrition by analysing the effects of soil type on mortality of children living in five rural parishes in southern in Sweden, for the period 1850-1914. Mortality differed greatly among regions in Europe before and during the mortality decline. These differences were not only common between rural and urban areas, but also between close by rural areas (Bengtsson and Dribe, 2010, 2011; Claësson, 2009; Gregory, 2008; Van Poppel, Jonker, and Mandemakers, 2005). Studies covering the same area and a similar period as this paper have found large differences between parishes in both childhood and adult mortality after controlling for socio-economic and other family factors. In fact, the regional differences were often larger than the socio-economic ones, indicating that place was a stronger determinant of mortality than living standards (Bengtsson and Dribe, 2010, 2011). Possible explanations for the mortality differences are variations in the distribution of risk factors related to the exposure, or the resistance, to diseases, or both.

Although the wide-spread epidemics and other highly virulent diseases (both with a low socio-economic gradient) had decreased in 19th century Sweden, they were still a major cause of death (Bengtsson and Lindstrom, 2000; Quaranta, 2013). Several factors affecting the exposure to such diseases in the time period considered in this study varied across regions. For example, access to safe water and sanitation, housing conditions, population density, public health implementations, poor relief, and breast feeding practices (Brändström, 1984; Brändström, Edvinsson, and Rogers, 2002; Claësson, 2009; Floud et al., 2011; Kintner, 1985; Lazuka, Quaranta, and Bengtsson, 2016; Woods, Watterson, and Woodward, 1988). The spread of contagious diseases may also have been influenced by the characteristics of the environment, such as the topography and the accessibility through communication networks, which may determine the interaction patterns between people. In addition, the microclimate (e.g., the temperature and humidity), affected by e.g., soil conditions and topography, could, possibly, influence the exposure to diseases such as the common cold and respiratory diseases (Munro et al., 1997). Lastly, vector-borne diseases such as malaria were common in Europe until the 20th century (they disappeared foremost because of climate variations, drainage of wetlands, increased living standards and better nutrition). Because wetlands and areas with certain beneficial soil conditions served as habitats for mosquitos transmitting malaria, residing close to such areas would likely increase the exposure to diseases (Dobson, 1994; Lindgren and Jaenson, 2006; Patz et al., 1998; Schröder and Schmidt, 2008).

As a consequence of the mortality decline in the beginning of the 19th century, in which a decline in the virulence of the pathogens likely occurred (Fridlizius, 1984), diseases affected by the nutritional status became increasingly a more important determinant of mortality in Sweden. In pre-industrial rural societies, factors affecting nutrition were commonly the ones that determined the ability of individuals to support themselves from the land they owned or worked on. In addition to the size of the farm and its arable land, variations in the natural environment such as soil conditions could affect the farm-level productivity and the caloric potential of the land, and hence the availability of food (Bohman, 2010; Brunt, 2004; Puleston and Tuljapurkar, 2008). Such differences in farm-level output would therefore manifest themselves as a socio-economic gradient in mortality. Mortality differences among the social classes were, however, small for adults until the 20th century in Europe (Bengtsson and van Poppel, 2011). On the other hand, socio-economic mortality differences existed for children in the study area during the latter part of the time period considered in this study (Bengtsson and Dribe, 2010), which indicate an influence of nutritional status on mortality.

The aim this study is to better understand the role of nutrition on child mortality, in general, and in the mortality differences which have been found previously among the five Scanian parishes considered in this study (c.f. Bengtsson and Dribe, 2010, 2011). Because large differences in mortality between the rural areas have been found also after controlling for various socio-economic factors, there are indications of other factors in play that affected the mortality. Such factors could be those that determine the exposure to virulent diseases and which have a low social gradient. Alternatively, the commonly used measures of socio-economic status may not fully capture the differences found in the nutritional status of individuals. As regards to the latter, historical datasets (for rural areas) containing longitudinal and individual-level economic information on income and farm-level productivity are sparse. This is also the case for our study area. To overcome this problem, previous research has employed socio-economic measures based on access to land, using taxation information, and type of land (manorial or freehold) (e.g., Bengtsson, 2004). For the time period considered in this paper, however, taxation information is sometimes an inaccurate measure of the farm-level productivity (cf. e.g., Svensson (2001)). Therefore, as a new measure of nutrition, we use information on the underlying soil type for each farm. We estimate this variable using individual-level longitudinal data from the Scanian Economic Demographic Database (SEDD) in combination with unique micro-level geographic data. Such information is available because we have recently linked individuals in the SEDD database to the property units they lived in for the period 1813-1914 (Hedefalk, Harrie, and Svensson, 2015). By combining such detailed residential histories with detailed information on soil type for each property unit, we can use the soil type as an indicator of the farm-level agricultural productivity. This information can therefore be used as an estimate of the nutritional status for the individuals residing in the property units. Because soil types varied between and within regions, they may explain some of the spatial mortality differences found previously between the five parishes.

We analyse the effects of soil type on mortality of children aged 1-15 for the period 1850-1914. Children aged 1-15 are studied because they were sensitive to malnutrition as well as to environmental factors (Bengtsson, 1999; Rocklov et al., 2014; Schumann et al., 2013; Wolleswinkel-van den Bosch et al., 2000), and the regional differences in mortality were usually larger among them (Van Poppel et al., 2005). As a sensitivity test we also analyse infants (age 0-1) to compare the two age groups. The focus is, nevertheless, on child mortality; it is in general more dependent on family income and living conditions compared to infant mortality which is mainly affected by care such as breastfeeding (e.g., Bengtsson, 1999; 2004; Oris, Derosas, and Breschi, 2004). Moreover, we expect that the impact of soil on child mortality will vary based on whether the family depended on their land for income and nutrition. Therefore we categorize the children into three groups: large-scale farmers, small- and medium-scaled farmers, henceforth called farmers, and labourers (cf., Section 5.1). Using a rudimentary indicator based on taxation information and area of the properties in which individuals lived, we define farmers as those having land that was large enough to provide at least the majority of the earnings needed for subsistence. Families having smaller and less productive lands than the farmers, including the landless, are defined as labourers. Lastly, the large-scale farmers constitute a small group of the most well-off individuals.

We foremost contribute to the literature on how the geographic context may affect child mortality by focusing on the following two hypotheses.

1. Our main hypothesis is that soil type affected the farm-level agricultural production patterns, and the quantity and quality of the output; e.g., the choice of crops and the magnitude of the yield. This, in turn, affected the nutritional level of the children and thus their likelihood of dying. We expect that children living on farms covered by relatively large areas of fertile soils, such as clayey till or clay, experienced lower mortality than children living on farms with less fertile soils. Moreover, given that soil type is an indicator of farm productivity and therefore also of nutrition and resources, it should primarily affect the mortality of farmers, i.e., children to individuals owning or leasing land. Labourers, which were mostly paid in money or in kind, as well as the large-scale farmers, on the other hand, should be less affected by the soil type. Finally, we expect stronger effects of soil type on mortality from non-virulent and nutrition dependent diseases compared to highly virulent airborne-infectious diseases such as whooping cough and smallpox.
2. As an alternative hypothesis, soil type may instead be a measure of exposure to virulent diseases. If so, we expect soil to affect the mortality of all social groups equally. In addition, there should be stronger effects of soil on mortality from highly virulent airborne-infectious diseases.

To our knowledge this is the first longitudinal study on the micro-level that analyses the effects of soil type on mortality in a historical rural society. Previous and related research has often used geographic macro data on larger administrative units and therefore much detail has been lost. The main reason is that large historical datasets in which individuals are linked to micro-level longitudinal geographic data are sparse. It should be noted, however, that we have limited information on several common factors affecting the exposure to diseases, such as sanitation, wetlands, road networks etc. Therefore, we cannot currently control for such factors, which is a limitation with this study.

2. Previous research

The relationship between environmental factors such as soil conditions and productivity in modern societies has been well researched and several indices and models for soil conditions have been developed (Doran and Parkin, 1994; Jaenicke and Lengnick, 1997; Steduto et al., 2009). A broad literature is also available on the impacts of soil on human health. Such impacts can be direct or indirect. Direct effects are those foremost related to various pathogens contained in the soil (Oliver and Gregory, 2015). Children are particularly exposed to such pathogens due to their willingness of eating soil (Hawley, 1985). Indirect effects are primarily factors such as soil fertility which affect the quantity and the quality of the food produced (or the kind of food that can be produced). In addition, trace elements and minerals in the soils are transferred to the food cultivated in it, which in turn affect the health of humans (Abrahams, 2002; Oliver and Gregory, 2015). For example the availability of elements such as iron, iodine, selenium and zinc (Oliver and Gregory, 2015), which are essential to human health, is highly linked to soil quality.

There are a few studies that have tried to quantify the impact of local soil conditions on agricultural production patterns in a historical context (Allen, 2008; Brunt, 2004). For example, Brunt (2004) used village-level data to analyse the effects of technological developments and environmental factors on English agriculture in the 18th century. He found that technological applications such as drainage, turnip cultivation (which increased the hummus content in the soil and thus reduced the weeds), clover cultivation (which added nitrogen into the soil) and seed drills, increased the yields substantially. As regards to the environmental factors, climate was shown to be a much more important factor affecting the crop yield than soil quality (note, however, that the study used soil type data on a more aggregated level than what is used in our study). Furthermore, Allen (2008) analysed the importance of nitrogen in the soil and its relationship to yield in preindustrial England and found that nitrogen-fixing plants such as peas and beans accounted for approximately half of the yield increase during England's agricultural revolution. Thus, the local production pattern at each farm likely affected the fertility of the soil types. Moreover, there have been several theoretical demographic models developed that can be used to model feedbacks between food supply, vital rates and labour availability in preindustrial societies. Using such models it is possible to analyse how environmental and soil conditions as well as human factors such as agricultural techniques and crop choices could affect mortality and fertility rates (Lee and Tuljapurkar, 2008; Puleston and Tuljapurkar, 2008). In a case study applying such models, Lee and Tuljapurkar (2008) found that both the cultivated area and the soil productivity positively affected the population size for preindustrial societies.

Moreover, using parish-level data to analyse the effects on mortality of short term economic stress and how such effects differed among pre-industrial farming regions, Dribe, Olsson, and Svensson (2011) found that, for the period 1750-1860, the robustness against harvest failures differed greatly among the three common farming regions in Sweden (plain lands, brushwood and forest lands). The effects diminished, however, as a result of the agricultural transformation in the beginning of the 19th century. Furthermore, Bohman (2010) analysed the impacts of natural conditions, markets, and technological developments on the agricultural production patterns in pre-industrial southern Sweden before and after the enclosures that were implemented during the period 1800-1850. The study found that, in addition to an increased importance of markets (due to a growth of domestic and foreign markets), the implementation of enclosures increased the importance of natural conditions for the individual farmers in the 19th century, and the farming regions became less important. Consequently, the differences in productivity changed from being regional to local in line with the enclosures.

Finally, the effect of climate on mortality in pre-industrial societies has been studied combining micro-level and macro-level data (Bengtsson and Broström, 2010; Rocklov et al., 2014; Schumann et al., 2013). For example, Schumann et al. (2013), using parish-level data, found that for a rural region in northern Sweden in the 18th and 19th century, high amount of autumn rains increased the total number of deaths (for all age groups). The authors speculate that these higher level of rains reduced the harvest quality, which in turn affected the nutritional status and hence the susceptibility to infectious diseases. In addition, the rains may also have increased the spread of air-borne diseases due to crowding (i.e., people stayed inside during rainy weather). Moreover, Bengtsson and Broström (2010) found that cold winters increased the mortality among adults but not among children and infants, indicating that different age groups are affected by climate variations in different ways. Finally, as regards to soil type as a factor affecting the micro-climate, Munro et al. (1997) studied the relationship between infant mortality and soil in England for the period 1981-1990. Using ward-level data they found that wards dominated by wet soils had 31.9% higher infant mortality than wards dominated by dry soils. It is speculated that areas with wet soils contains in general humid and cold air, which may increase the risk of cold and other diseases for the infants and their mothers (Munro et al., 1997). Thus, although research shows that infant mortality is in general less dependent on environmental factors compared to child mortality, soil types may, nevertheless, affect the mortality of infants.

3. Context and study area

The time period of this study covers several changes in the agricultural production and the market in Sweden. In the beginning of the 19th century, technical improvements such as better ploughs and the increased use of horses made it possible to cultivate lands that had not previously been suited for agriculture, foremost fertile, but heavy, clay soils which had required much workforce and which often became waterlogged. Such soils became increasingly used for grain production (Gadd, 1983, 2011). Moreover, the implementation of the enclosures increased the importance of natural conditions for the individual farmers in the 19th century. Before these land reforms, every field in a village was divided into smaller plots which were shared among the farms, and therefore the soil conditions were quite equally distributed among the farms. After the land reforms, however, the plots of each landowner were consolidated into single landholdings, resulting in an increased variation of soil conditions between farmers (Bohman, 2010). Furthermore, in around 1880 livestock production became more important and the commercial production was intensified. In Sweden as a whole there was also a decreased profit in grain production. This meant that much of the new land reclamation that occurred until 1880 had stopped (Morell, 2011). In addition, with an increased livestock production, fertilisers became more available which likely improved the soil conditions. There was also a more extensive use of new crops which resulted in the possibility to increase crop yield on less productive soils. Moreover, with a more developed market, it was possible to produce a surplus of output. Large farms in the plain land regions could therefore better specialize in producing grains, whereas smaller family farms were better suited for livestock production (Pettersson, 1989).

The study area covers five rural parishes located in Scania (the southernmost region in Sweden), namely Hög, Kävlinge, Kågeröd, Sireköpinge and Halmstad (Figure 1). These parishes are not a representative sample of Sweden, but they vary in their topography and socio-economic characteristics (Dribe and Bengtsson, 1997). As regards to the topography, Hög, Kävlinge and Sireköpinge were plain land farming regions (open farmlands) which in general focused on grain production. Kågeröd was a forest region with large forest areas; Halmstad a brushwood region with wooded areas in the north and plain lands in the south (Dribe et al., 2011). Moreover, Sireköpinge, Halmstad and Kågeröd had primarily a manorial system in which tenants leased their farms for a certain time period; in Hög and Kävlinge freeholders and crown-tenants were more common, who owned their land and paid taxes for it. Furthermore, Hög and Kävlinge underwent a major enclosure in 1804, in which most of the farmers moved out from their villages into their property units. Halmstad was enclosed in 1827 and 1844, Kågeröd in the period 1839-1842, and Sireköpinge in 1849. All parishes stayed rural and had a similar economic structure and development as well as population growth for the whole study period, except for Kävlinge which developed into an industrial town in the end of the 19th century.

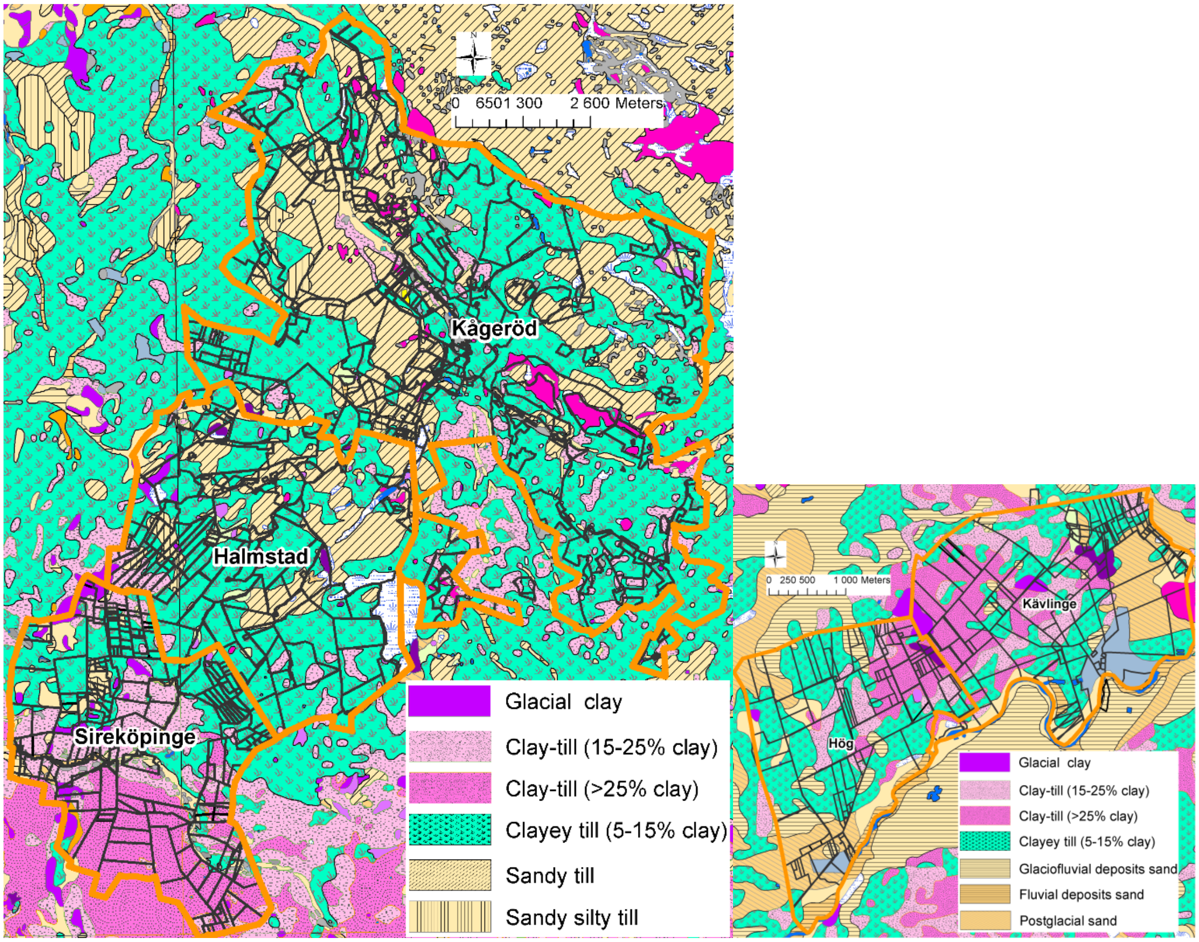


Figure 1: Common soil types in: 1) Sireköpinge, Halmstad and Kågeröd; 2) Hög and Kävlinge. The legend shows only some of the most common soil types. The black lines represent the property unit borders in 1910; the orange lines represent the parish borders (Source: SGU (2014)).

Moreover, the soils within the study area are among the most fertile ones in Sweden, especially in the plain lands. Sweden is mainly dominated by the postglacial soil till/moraine, and the most fertile soils are foremost clayey till (clay content 5-15%) and clay-till (clay content 15% and above). Clay soils are also fertile in general, although the clay content and the topography have a big influence (Eriksson et al., 2005). For example, clay soils in low lands have usually an increased risk of becoming waterlogged (Bohman, 2010). In addition, clay soils as well as clay-tills with high clay content are generally heavy to work with and required more plough animals than lighter soils. Sandy soils, on the other hand, require a lower work force, but they are also less fertile. The soil types of the areas considered in this study constitute approximately 25 detailed soil type classes (Figure 1). The most dominating ones are variations of till: sandy till, clayey till, coarse clay-till (15-25% clay content) and fine clay-till (clay content above 25%). Various sand soils and clay soils are also quite common.

4. Data

We use individual-level longitudinal data from the Scanian Economic Demographic Database (SEDD), created by the Centre for Economic Demography, Lund University, in collaboration with the Regional Archives, Lund (Bengtsson et al., 2014). The dataset for analysis was created using the program developed by Quaranta (2016). The SEDD includes demographic and economic information on all inhabitants that have lived in the five parishes from 1646 to the present. In this study we use a subset of the SEDD for the period 1850-1914. Note that individuals living in the urban area of Kävlinge town are excluded because they were not likely to be affected by the soil type within the town. The database contains continuous information on the family and household structure, on the dates of birth, marriages, and death taking place in the parishes, and on the years of the individuals' migration within and between the parishes. The causes of death have also been registered from 1750 and onwards. The primary sources for the SEDD are vital registers, catechetical examination registers/parish registers and annual poll-tax registers. The catechetical registers start from 1815, which means that the information about the individual exposure and household structure used in this study is well covered. Moreover, the data quality of the births and the infant deaths has been evaluated by estimating the birth sex ratio and the share of infant deaths occurring during the first months of life for different social groups (Bengtsson and Lund, 1994, Bengtsson and Dribe, 2010).

In addition, we have information about the detailed geographic location of each of the individuals that have lived in the five parishes. In a recent study we have combined historical maps and demographic information from SEDD to link around 53,000 individuals in the five rural parishes, for the period 1813-1914, to the property units they have lived in (Hedefalk et al., 2015). The property units are stored in temporal representations of longitudinal object lifelines. That is, for each property unit we have yearly information about when it was created, reformed and when it ceased to exist. This information is derived from cadastral dossiers and textual sources such as poll-tax registers (Hedefalk et al., 2015). Consequently, we have information about the residential histories of the individuals and about the shape of the property units which was updated on an annual basis.

With regards to the quality of the geocoding, the linkage between the poll-tax registers and the digitized property units has been carried out on two level of detail: on the exact property unit and on the address level (when property units were subdivided or partitioned into smaller units, they did not receive new designations; thus, multiple close-by property units may share address). For Kävlinge, Halmstad, Kågeröd and Sireköpinge, 50% of the property units in the poll-tax registers have been linked to the exact corresponding digitized property unit; for Hög parish, such link level is 85%. Moreover, 94% of the property units (all parishes) in the poll-tax registers have been matched to a digitized property unit on the address level (Hedefalk et al., 2015). Soil type data on the exact property unit level is used when such linkage exist; otherwise, soil type data on the address level is used. As regards to the share individuals that for parts of, or for their whole life course, could not be linked to a property unit, 10.9% of the children's (aged 1-15) time at risk are unlinked in the dataset used in this study. Finally, the absolute positional accuracy of the digitized property units used in this study is estimated to be approximately 25 metres (i.e., the average distance between a property unit border in the dataset and its corresponding border in the true world).

The soil type data were obtained from the Swedish Geological Survey (SGU). The information builds on mappings and field surveys that began in the 1960s and is ongoing today (SGU, 2014). Common for all the data is that the observations have been conducted on around half a meters depth; i.e., under the food soil. For our study area, the soil types have been estimated through a detailed field work, and the data quality is assumed to be homogenous across the regions (SGU, 2014). The positional accuracy for the soil types used in this study is approximately 50-75 metres. It should also be noted that the defined spatial boundaries of the soil types are often not sharp. Instead they mark transition zones of the soil types (SGU, 2014).

5. Methods

This study focuses on the period after the large land reforms had taken place in all of the five parishes; i.e., from 1850 to 1914. Before these enclosures, the effects of soil type were small for individuals within a parish. We begin at age 1 and consider children until the age of 15, which was when they usually left home (Dribe, 2000). The main independent variable of interest considered is the soil type of the property units in which the children resided.

5. 1. Variables used in the analyses

We control for various socio-economic and family-level factors which are explained in the following paragraphs.

Soil type coverage - To create a variable defining the soil type where the children resided, the spatial coverage of each soil type within every property unit is estimated. Here, the geometric intersection is computed for each property unit and soil type (shown in Figure 1). Thereafter, the percentage of the spatial coverage for soil types is estimated. Lastly, the individuals are linked through the poll-tax registers and other sources to the digitised property units that they have lived within (cf. Hedefalk et al. (2015)). The soil type classes are thereafter aggregated into seven groups: Water, Rock, Peat, Clayey till (till with a clay content of 5-15%), Clay-till/clay soils (including coarse and fine clay-till with clay content 15% and above), and Sandy soils (including gravel and sandy till soils). Finally, one categorical variable is created based on the spatial coverage of each soil type group. The variable groups represent large spatial coverage of the soils: 50-75% or 75-100% of clayey till, 50-100% of either clay-till/clay soils or sandy soils, and mixed soils. The mixed soil type is the smallest group (cf. Table 1) and represents areas that do not have large proportions of any specific soil type. This group is, nevertheless, primarily constituted of clayey till, sandy soils and clay-till/clay soils. The Clayey till group is split into the two categories 50-75% and 75-100% because the large proportion of this soil in the study area (see Table 1). We expect that areas with large coverage of clayey till or clay-till/clay are more fertile than sandy soils. Additionally, the clayey till soils may have been less difficult to work with than the heavier clay-till/clay soils (Eriksson et al., 2005; Bohman, 2010). Therefore, we expect that farmers' children who lived in property units with higher spatial coverage of clayey till experienced relatively lower mortality as a result of higher levels of nutrition. Because the mixed soil type group is heterogeneous, it is difficult to make assumptions about children living in areas covered by such soil.

Socio-economic status (SES) – This variable is based on the children's family's access to land and the ability to support themselves with that land (and whether they were able to employ labour or not); i.e., having land above subsistence level (cf. Bengtsson and Dribe (2010)). Such ability was related to having a taxation value (Swedish *Mantal*) higher than, or equal to, 1/32. A higher value, 1/16, is used in the study by Bengtsson and Dribe (2010), but this value reflects the subsistence level in the first half of the 19th century and earlier. The Swedish taxation values remained static despite improvements in productivity. Thus, 1/32 is a more accurate limit of the subsistence level in the second half of the 19th century (cf. Svensson (2001, pp. 66-67)). The following four variable groups are created (Table 1).

- Freeholders and crown tenants with land of at least subsistence level.
- Noble tenants having time-limited leasing agreements on manorial lands above subsistence level.
- Semi-landless individuals, which contained: a group including freeholders, crown tenants and noble tenants with land below the subsistence level, as well as crofters and cottagers with or without lands that were similar in size to the former group.
- Landless individuals, foremost soldiers, workers and servants.

When constructing these groups, the individuals belonging to the highest class (foremost the nobility in our dataset) were excluded, including the owners of the large manors. This group was excluded because it was too small in numbers to constitute an own group. Moreover, because of the structure of the poll-tax registers, all individuals within the same family are assigned the same taxation value. This means that children to servants who belonged to the same family as their household head were assigned the taxation value of the property owned by the household head. By contrast, children to servants who constituted their own household or family, which often lived in separate buildings, were classified according to the taxation value of their parent's property (commonly of zero value). Thus, we make the assumption that children to servants living within the same family as the household head were in general better off than children to servants constituting their own household (as a sensitivity test, we also estimated models where every servant was classified as landless, but the results did not change).

Taxation value – A ratio (continuous) value used as a measure of wealth.

Parish of residence, sex and birth year.

SES v2– Because we expect soil to primarily affect the mortality of those that are dependent on their land for subsistence, we introduce a new measure of SES that categorizes the families into three groups based on taxation value and area, but not on land type: *large-scale farmers*, *small- and medium-scaled farmers,* henceforth called *farmers*, and *labourers*. As stated earlier, farmers constitute a group who owned properties that were large enough to at least provide them with the majority of the earnings needed to support themselves. Families having smaller and less productive lands than the farmers, including the landless, are defined as labourers. Lastly, the large-scale farmers constitute a small group of the wealthiest individuals. Below follows a detailed description of the categorization of the variable groups.

- Large-scale farmers
    - Families having lands with a taxation value higher than 2/5 *mantal*.
    - Families with lands larger than 100 hectares and with a taxation value of at least 1/32 *mantal* (the threshold of 1/32 is set to exclude possible landless and semi-landless families working on large farms).
- Farmers
    - Families with lands that are 2-100 hectares and which have a taxation value of at least 1/64 *mantal* and at most 2/5 *mantal*.
    - Families with lands larger than 100 hectares and with a taxation value between 1/64 and 1/32 *mantal*.[1]

[1] These two groups are somewhat problematic. They may e.g. represent individuals with large and unproductive, or small and productive, lands, but also individuals with incorrect taxation information, or individuals working on large farms. However, the groups are small and constitute in total only 0.46% of the children's total time at risk.

- Families with lands smaller than 2 hectares and with a taxation value between 1/64 and 2/5 *mantal*[1].
- Labourers
  - Landless families.
  - Families with lands smaller than 2 hectare and with a taxation value below 1/32 *mantal*.
  - Families having lands with a taxation value below 1/64 *mantal*.

When defining the SES variable, we considered lands with a taxation value of 1/32 or higher as a threshold for families being able to support themselves with that land (Svensson, 2001). Therefore, a taxation value of half the size of this threshold; i.e., 1/64, is used as a lower limit for defining the farmers group. The upper limit for the farmers is set to 2/5 *mantal* because when using thresholds larger than 2/5, the models violated the proportional hazard assumption of Cox models for the continuous taxation value variable. Furthermore, lands with 2 hectares are considered as the lower limit for small-scale farms, whereas 100 hectare is considered as the lower limit for large-scale farms (cf. Morell (2011)). We employ this new categorisation to enable the explicit study of those children; i.e., the farmers' children, whose nutritional status, and hence mortality, should be most affected by the underlying soil type of the property unit.

Note that some of the selected limits of the area and taxation values that define the groups are arbitrary, as these limits are both time and context dependent. For example, the threshold of 2/5 *mantal* used as an upper limit for the farmers group. Therefore, as a sensitivity test, we also estimated models with other limits of taxation value and area. These results show that the effect of soil type on child mortality increases slightly when lowering the upper limits of the taxation value and area (not reported here) for the farmers group, which indicate that the smaller the farm was, the more sensitive its family may have been to the underlying soil type.

Explanatory variables used for sensitivity tests – As a sensitivity analysis we estimated models that also controlled for property unit area, population density, land type, and whether children lived in large demesnes/satellite units were included in various sensitivity analyses. Further details on these variables are provided in Appendix 1. It should be noted that he property unit area was positively correlated with the taxation value (0.407 for areas below 100 hectare), and tests showed that taxation value was a more accurate predictor for child mortality than area. Therefore, the property unit area was excluded from the main models, which instead considered taxation value.

5.2. Statistical analysis

We estimate different models that consider as outcome mortality of children aged 1-15. Control variables are introduced in a stepwise manner in order to observe changes in the effects by adding additional variables and also to be able to compare the findings to previous results. The study focuses primarily on mortality from all-causes as an outcome, but we run separate models that consider specifically death from airborne-infectious diseases and from non-airborne infectious diseases as outcomes. The following models are estimated:

- *Model 1a (Parish-SES)*. Explanatory variables: parish of residence, SES, gender and birth year.
- *Model 1b – Non-airborne (Parish-SES)*. Explanatory variables: Model 1a. Analyses the mortality risk from non-airborne diseases in order to better identify deaths that could have been caused by the lack of nutrition (cf. Table2).
- *Model 1c - Airborne (Parish-SES)* [2]. Explanatory variables: Model 1a. Analyses the mortality risk from only airborne diseases in order to better identify deaths that could have been caused by increased exposure to highly virulent diseases.
- *Model 2 (Parish-SES v2)*. Explanatory variables: parish of residence, SES v2, gender and birth year.
- *Model 3 (Parish - Tax)*. Explanatory variables: parish of residence, taxation value, gender and birth year.
- *Model 4 (Parish – Soil type)*. Explanatory variables: parish of residence, taxation value, gender and birth year.
- Model 5a (*Parish - SES v2 - Tax - Soil type*). Explanatory variables: parish of residence, soil type, taxation value, SES v2, gender and birth year.

[2] It was not possible to estimate models for only airborne infectious diseases for the farmers' children due to the small sample size. Such models were possible to estimate for all the children and for the labourers' children.

- Model 5b – Non airborne (*Parish - SES v2 - Tax - Soil type*). Explanatory variables: Model 5a. Outcome: mortality from non-airborne diseases.
- Model 5c - Airborne (*Parish - SES v2 - Tax - Soil type*)[1]. Explanatory variables: Model 5a. Outcome: mortality from airborne diseases.

Likelihood Ratio (LR) tests are used to analyse whether the addition of variables in the extended models improved model fit. A separate model is run for infants as a sensitivity analysis to test if their mortality is affected by soil type. Moreover, except for Model 1b and 1c, the models are also estimated separately for children to labourers and small and medium-scaled farmers. For models 1-5, Cox proportional hazard models are used (Therneau and Grambsch, 2000), whereas a competing-risks regression model is used for Model 1b-c and Model 5b-c (Fine and Gray, 1999). All Cox proportional hazard models also included a shared frailty component to measure the proportion of unobserved characteristics that are shared between members of the same household. That is, theta's were obtained to measure within-household variation in mortality. Because of the spatial autocorrelation[3] for the soil types we also tested models with property units as a shared frailty (not reported here), but this did not change our results. Tests based on Schoenfeld residuals were conducted after each model to test the proportionality of the hazards, and no violations in this assumption were found in the main explanatory variables. Finally, correlation could be observed between some of the soil type groups and parishes and, in some degree, between soil type and SES, which indicates a possible redundancy between the variables. There were also overlaps between parish and SES. That is, freeholders foremost resided in Hög, Kävlinge and Kågeröd, whereas tenants commonly lived in Sireköpinge, Halmstad and Kågeröd; the groups considered in the newly introduced measure of SES (SES v2), landless and semi-landless, however, were more equally distributed among the parishes. We tested for multicollinearity by estimating linear regressions including soil and parish and thereafter checked the variance inflation factor (VIF). These tests showed no indication of such multicollinearity issues between

[3] Moran's I, a measure for spatial autocorrelation, was found to be only 0.05 for the detailed soil types covering the study area (shown in Figure 1), but higher for the specified soil type variable group (Figures 2-3). For example, for the period 1900-1914, Moran's I was 0.29 (p-value: 0.00) for the whole study area, 0.30 (p-value: 0.00) for the region covering Kågeröd, Halmstad and Sireköpinge, and 0.07 (p-value: 0.14)) for the region covering Kävlinge and Hög (Figures 2-3). The latter indicates an insignificant spatial autocorrelation for Hög and Kävlinge, which may be explained by their small area.

the variables. Hence, the variables likely explain different parts of the variations in mortality in the model.

5.3. Descriptive statistics

Table 1 shows the distribution of the children's time at risk in percentage among the categorical variables considered in this study, and the average values of the continuous variables. The values for the taxation value represent only those individuals that had a value higher than zero. As seen in the table, farmers have a higher taxation value. The Unlinked soil type group represents the share of individuals that for parts of, or for their whole life course, could not be linked to a property unit. These individuals belonged foremost to the landless class and some of them were the poorest people who wandered about between farms and other lodgings. Consequently, it has been difficult to link them to a household or to a property unit. Table 2 shows 9 diagnostic categories of causes of death for the children in our study area. These groups have been created from 29 diagnostic groups (cf. Bengtsson and Lindstrom (2000) for a detailed description). All infectious diseases have been classified into three groups: airborne (e.g., smallpox, measles, scarlet fever, and whooping cough), food-borne and water-borne (e.g., nervous fever, typhoid fever, and dysentery), and others (e.g., blood poisoning, diarrhoea and other unclassifiable diseases). Moreover, the group "Other specified non-infectious diseases" include gastrointestinal diseases, psychiatric diagnoses, congenital heart disease, and kidney suffering. Table 2 shows that the largest groups of causes of death for both classes were the non-specified diseases, followed by the airborne diseases. The share of causes of deaths is almost identical between the two groups. Some differences, however, are observed; e.g., the labourers' children have a higher share of accidents and crimes, as well as food -and water-borne diseases. To create sufficiently large groups for the cause-specific models (presented in Tables 3-5), we study the mortality where the outcome is either from non-airborne/unspecified diseases or airborne diseases. Such classification has two limitations that may introduce biases in the analyses. First, the non-airborne/unspecified group is heterogeneous, with a very large share of cases not being specified. Second, approximately half of the deaths within the group airborne infectious diseases are caused by diseases such as different types of respiratory infections, measles and tuberculosis, for which the risk of infection may be influenced by an individual's nutritional status (cf. e.g. Bellagio conference authors, 1985). Therefore, we cannot estimate models for causes of deaths that are either explicitly linked to nutrition or not linked to nutrition (i.e., highly virulent diseases). Hence, the results from the cause-specific models have to be interpreted with care. Despite this limitation, analysing the mortality using such models is, nonetheless, a first step towards trying to better understand the influence of soil type, as an indicator of nutrition, on child mortality.

Table 1: Distribution of the time at risk in person-years on the independent variables used in this study, farmers and labourers, age 1-15, Scania 1850-1914.

	All	**Small- and medium-scaled farmers**	**Labourers**
	%	%	%
Soil type			
Clayey till 75-100%	20.43	22.28	20.60
Clayey till 50-75%	20.21	23.38	19.99
Clay-till/Clay 50-100%	21.81	29.20	19.69
Sandy soils 50-100%	17.10	15.24	17.43
Mixed	9.58	9.91	8.89
Unlinked	10.88		13.40
SES			
Freeholders	9.56	33.68	
Tenants	15.06	50.41	
Semi-landless	18.10	15.91	20.22
Landless	57.28		79.78
SES v2			
Large farmers	6.90		
Small-Medium Farmers	21.13		
Labourers	71.98		
Parish			
Hög	9.16	15.14	7.21
Kävlinge	8.32	9.18	7.61
Halmstad	19.41	24.28	18.98
Sireköpinge	27.85	27.14	28.26
Kågeröd	32.25	24.26	37.94
Sex			
Female	47.92	48.03	48.11
Male	52.08	51.97	51.89
Birth year (average and min-max)	1872.75 (1835-1912)	1871.43 (1835-1912)	1873.03 (1835-1912)
Taxation value (average and min-max)	0.27 (0.01-3.00)	0.15 (0.02-0.4)	0.01 (0.00-0.03)
Individuals	15485	3235	12900
Deaths	997	207	744

Table 2: Mortality by cause of death, farmers and labourers, age 1-15, 1850-1914. Total and relative frequencies

	Small and medium-scaled farmers		Labourers	
	Total	%	Total	%
Airborne infectious diseases	61	29.47	221	29.70
Food-borne and waterborne infectious diseases	8	3.86	50	6.72
Other infectious diseases	2	0.97	4	0.54
Cardiovascular diseases and diabetes	2	0.97	9	1.21
Accidents, crimes, etc.	1	0.48	21	2.82
Cancer	1	0.48	5	0.67
Other specified non-infectious diseases	23	11.11	79	10.62
Not specified	109	52.66	355	47.72
Total non-airborne infectious diseases/not specified	146	70.53	523	70.30
Total	207	100	744	100

Figures 2 and 3 show the spatial distribution of the soil type groups for all children aged 1-15. Note that the maps show all the property units that ever existed during each 10 year period. This means that some property units may overlay each other in the map, and that some property units may have existed only for a short period of time. Moreover, the empty areas in white represent property units where no individuals are linked. The large white area in Kävlinge parish represents the urban area that was excluded in the analyses (individuals living in this town were likely not affected by the underlying soil type). As regards to the soil type distribution, clay-till/clay soils dominate in the middle of Kävlinge and Hög, as well as in the southern parts of Sireköpinge (foremost clay-tills). Halmstad and Kågeröd are dominated by areas with large proportions of clayey till and sandy soils. Note also that the soil type variable seems to change for some property units through time. This is because the property units change size (e.g., because of subdivisions) through time and that larger property units are sometimes overlaid by smaller property units in the map. Hence, although the soil type is static, the soil type variable sometimes varies in time.

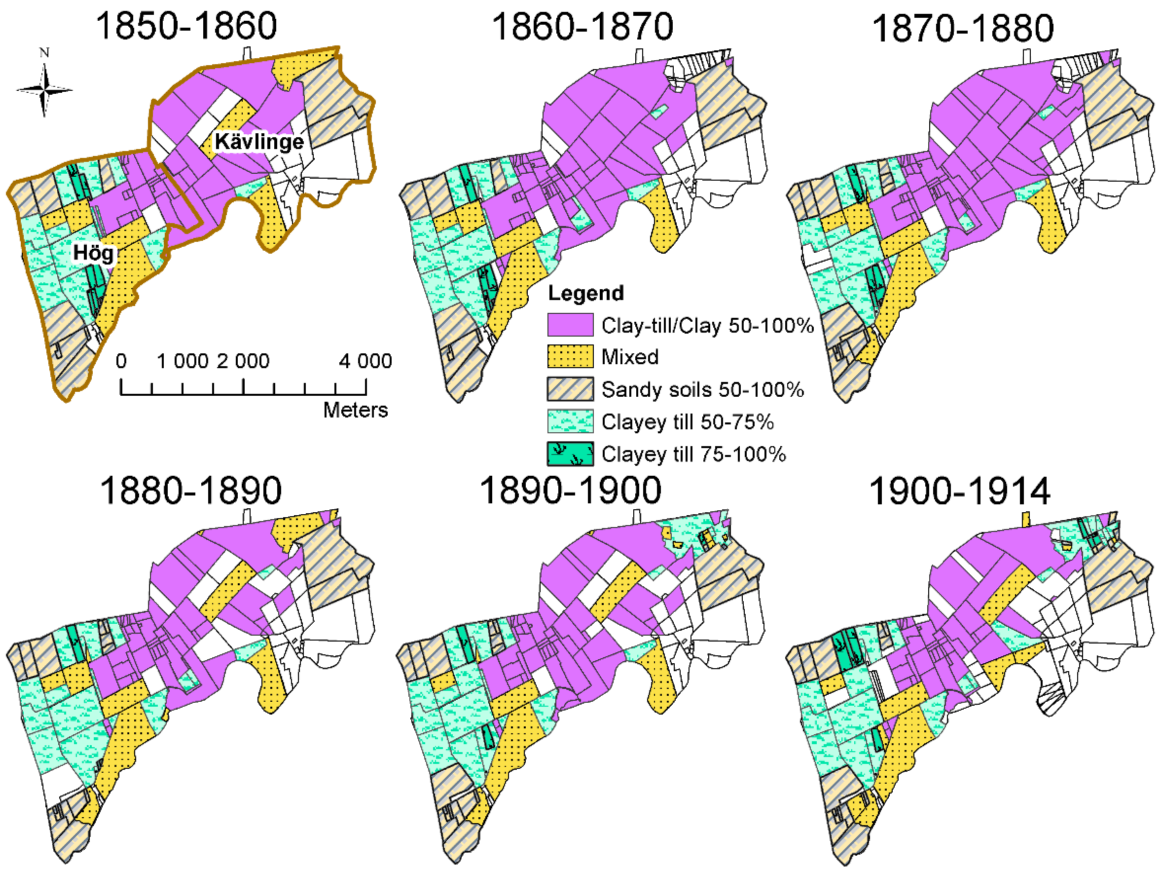


Figure 2: Distribution of the soil variable based on the percentage of the spatial coverage of soil types in each property unit in Hög and Kävlinge parish. The white areas represent property units where no individuals (children aged 1-15) are linked.

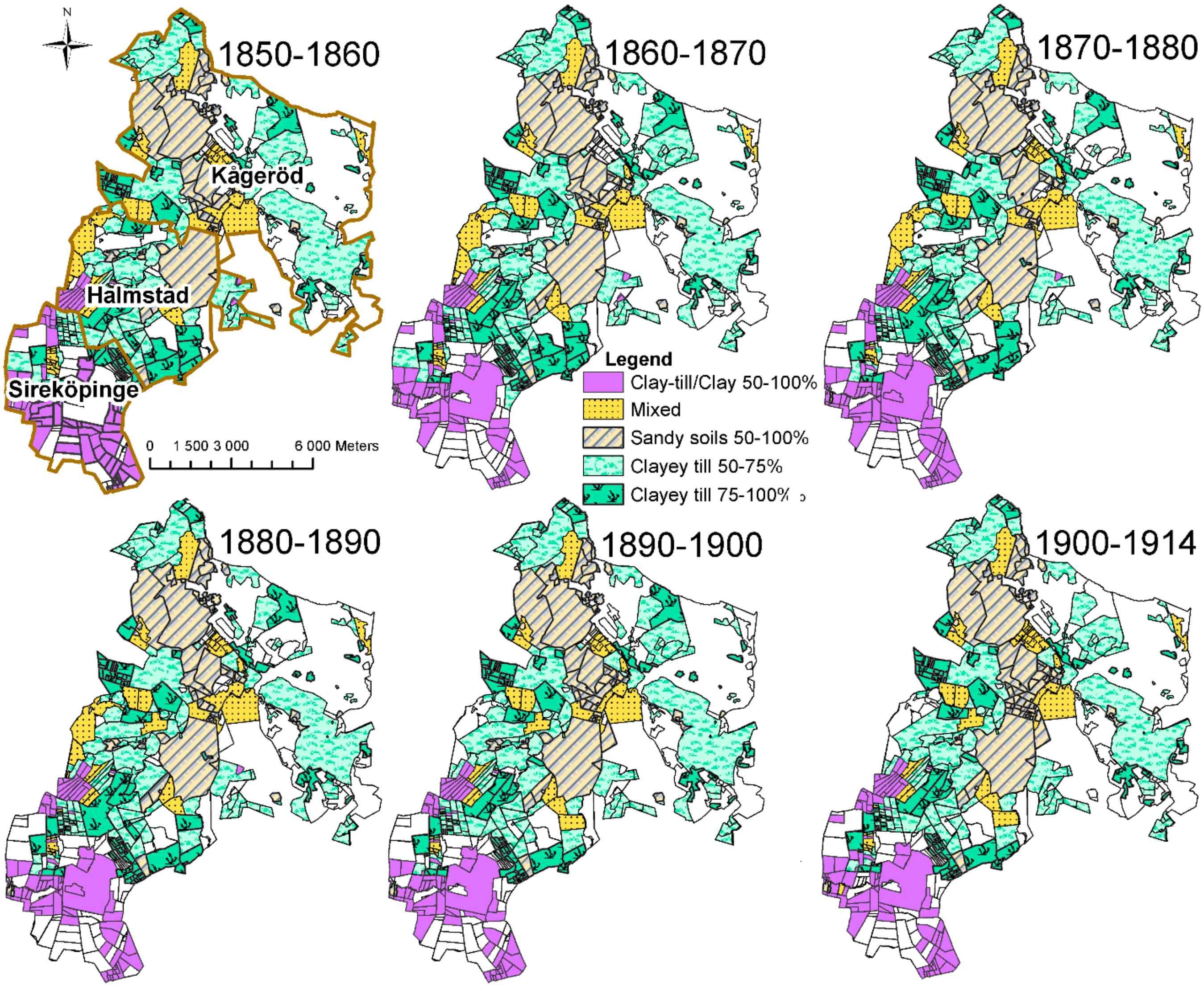


Figure 3: Distribution of the soil variable based on the percentage of the spatial coverage of soil types in each property unit in Sireköpinge, Halmstad and Kågeröd parish. The white areas represent property units where no individuals (children aged 1-15) are linked.

Moreover, figures 4a-d show the cumulative hazards of death for children aged 1-15 by SES, SES v2, parish of residence and soil type. Large socio-economic differences in mortality can be observed in Figure 4a and b. Here, freeholders (Figure 4a) and the large-scale farmers (Figure 4b) experience the lowest mortality. These mortality differences emerge also at an earlier age compared to the ones observed for parish of residence and soil type (Figures 4c-d). For the two groups studied separately in this paper (small- and medium-scaled farmers, and labourers, in Figure 4b) there are small or non-existing differences in their mortality levels. Moreover, Figure 4c shows that children living in the semi-urban parish Kävlinge experience the highest cumulative hazard of death, whereas the lowest cumulative hazard of death was found for the children living in Kågeröd. Lastly, mortality differences are also observed between the soil types groups, in which children living in property units with mixed soil types experience the lowest mortality, whereas the unlinked children have the highest risk of dying.

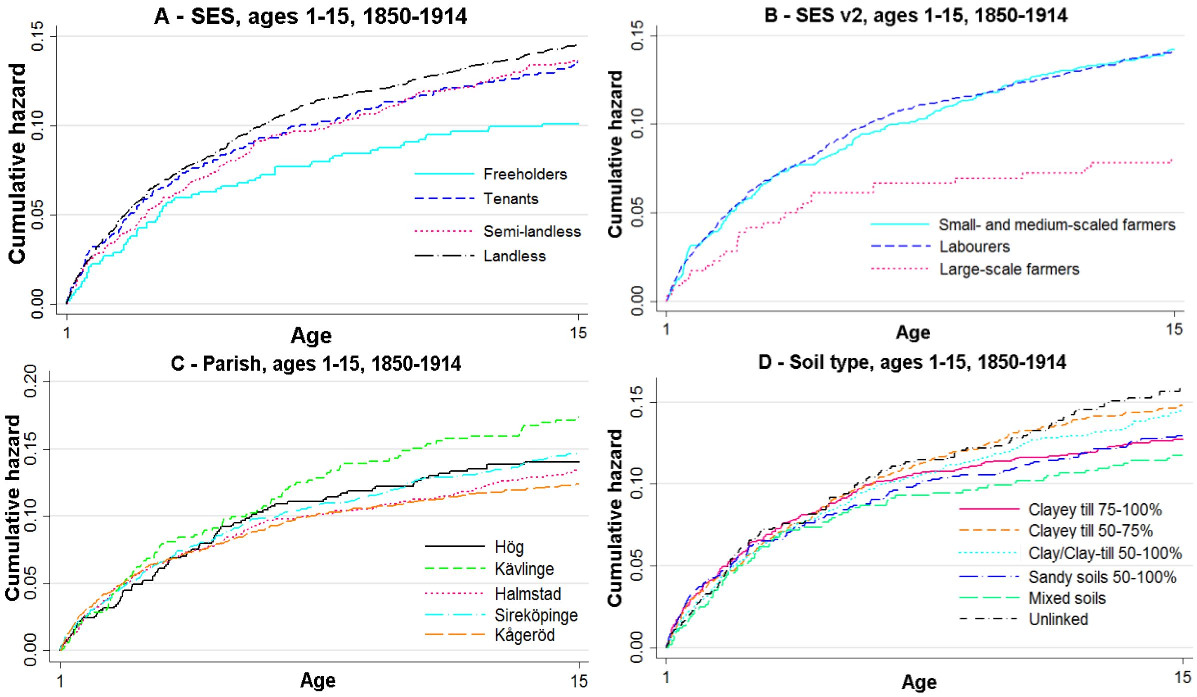


Figure 4: Nelson-Alen cumulative hazards by SES, SES v2, parish of residence and soil type, ages 1-15, 1850-1914.

6. Results

Table 3 shows the results from the models estimated for all children aged 1-15. No strong effects of soil types on mortality are revealed, which indicates that soil type may not be representative of the nutritional level of all groups of children. In addition, the only significant effect of soil type is found in the model that considers as outcome mortality from only airborne diseases (Model 5c).

In this model, children living in areas covered by 50-75% clayey till experience a 64% higher mortality risk compared to the reference category. In this model, also the unlinked group experiences a significantly higher risk of death. Moreover, we find consistent effects from parish, as previous studies have shown (e.g., (Bengtsson and Dribe, 2010)), also after controlling for the socioeconomic measures SES, SES v2, and taxation value (the magnitude of the effects and the statistical significance are, however, reduced for some of the parishes when introducing such controls in the models). Large mortality differences between the non-airborne/unspecified and airborne diseases for the parishes are also revealed (Model 1b-c), which remains also after controlling for SES v2, taxation value and soil type (Model 5b-c). In particular: compared to the reference category, children residing in Halmstad and Sireköpinge experience approximately 50% higher mortality risk from non-airborne/unspecified diseases, but nearly half the mortality risk from airborne diseases.

Furthermore, the freeholders (when considering the first SES classification) and large-scale farmers (when considering the second SES classification) experience a relatively much lower risk of death compared to the other social groups. However, in the cause-specific models, this effect is only statistical significant in the models estimated for airborne diseases. Hence, these results may indicate that some of the airborne infectious diseases are nutrition-dependent, or that the upper classes were less exposed to highly virulent diseases. Moreover, year of birth had a beneficial effect on children: an increase of one in year of birth decreases the mortality risk by 1% (Model 5a). Lastly, the model estimated as sensitivity analysis that focused solely on infants revealed no effects from parish of residence, social class and soil type; however, the soil type group "Unlinked" had a significantly higher hazard of death compared to the reference category (results not shown).

Because we expect the effect of soil type to primarily affect farmers', in Table 4 and 5 separate models are estimated for the children to labourers and small- and medium-scaled farmers (the large-scale farmers constitute a too small group to estimate separate models for them).

Table 3: Impact of soil type and other factors on mortality in Scania 1850-1914. Children aged 1-15.

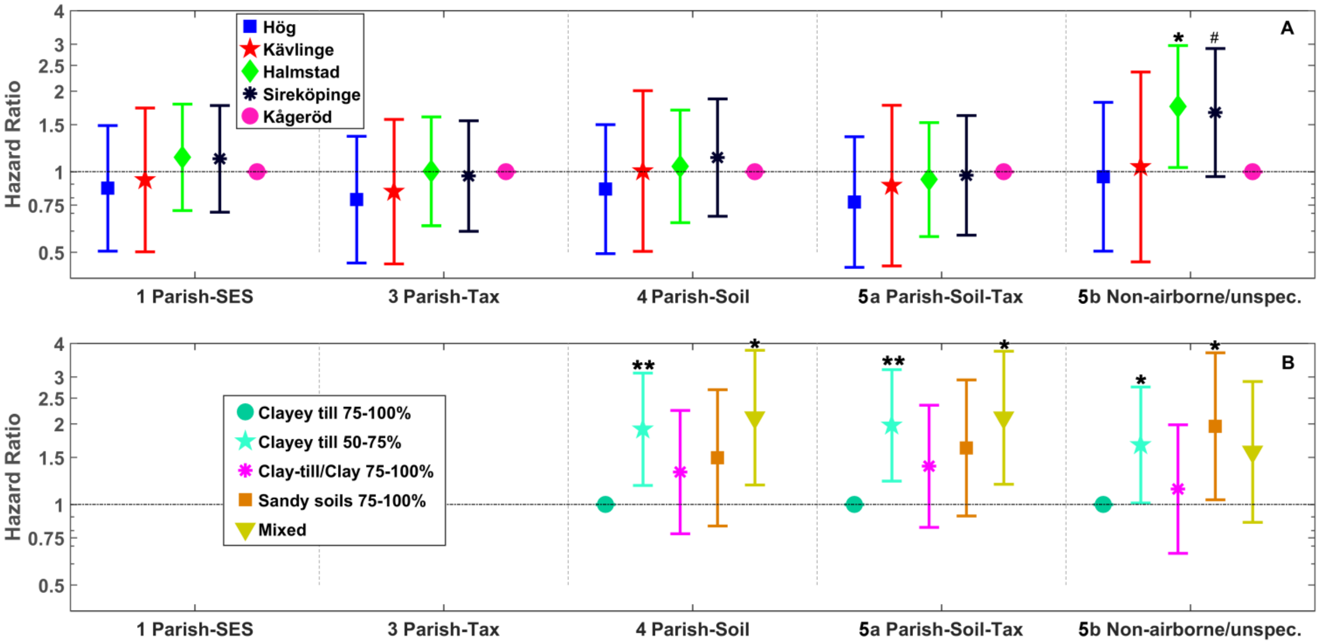
	1 Parish - SES						2 Parish - SES v2		3 Parish - Tax		4 Parish - Soil		5 Parish - Soil - SES2 - Tax					
	a All-causes		b Non-Airborne /unspecified		c Airborne		All-causes		All-causes		All-causes		a All-causes		b Non-Airborne /unspecified		c Airborne	
	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish																		
Hög	1.307	0.050	1.386	0.031	1.039	0.862	1.119	0.391	1.125	0.367	1.165	0.260	1.164	0.265	1.279	0.099	0.880	0.559
Kävlinge	1.581	0.000	1.271	0.123	1.966	0.000	1.434	0.004	1.421	0.005	1.425	0.008	1.422	0.009	1.226	0.204	1.674	0.006
Halmstad	1.085	0.433	1.417	0.001	0.501	0.000	1.075	0.486	1.094	0.388	1.133	0.236	1.111	0.318	1.447	0.001	0.510	0.000
Sireköpinge	1.179	0.074	1.510	0.000	0.625	0.003	1.174	0.080	1.182	0.069	1.225	0.054	1.215	0.064	1.560	0.000	0.660	0.020
Kågeröd	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc
SES																		
Freeholders	0.681	0.019	0.810	0.252	0.509	0.014												
Tenants	1.083	0.523	1.051	0.716	1.054	0.801												
Semilandless	1.000	rc																
Landless	1.157	0.123	1.184	0.109	1.070	0.672												
SES 2																		
Large-scale farmer							0.654	0.009					0.624	0.014	0.784	0.239	0.440	0.017
Small-Medium farmer							0.979	0.806					0.987	0.886	0.995	0.957	1.011	0.947
Labourer							1.000	rc					1.000	rc	1.000	rc	1.000	rc
Taxation value									0.852	0.169			1.074	0.641	0.854	0.268	1.349	0.195
Soil type																		
Clayey till 75-100%											1.000	rc	1.000	rc	1.000	rc	1.000	rc
Clayey till 50-75%											1.202	0.098	1.198	0.103	1.051	0.678	1.584	0.021
Clay-till/Clay 75-100%											1.035	0.765	1.039	0.737	0.952	0.688	1.225	0.345
Sandy soils 75-100%											1.089	0.482	1.097	0.445	1.082	0.545	1.209	0.391
Mixed											0.909	0.515	0.914	0.536	0.787	0.146	1.346	0.234
Unlinked											1.230	0.113	1.277	0.072	1.043	0.766	1.615	0.043
Birth year	0.990	0.000	0.991	0.000	0.985	0.000	0.990	0.000	0.990	0.000	0.990	0.000	0.990	0.000	0.991	0.000	0.985	0.000
Sex																		
Female	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc
Male	1.053	0.425	1.022	0.775	1.071	0.559	1.051	0.442	1.049	0.459	1.050	0.446	1.053	0.420	1.020	0.795	1.077	0.525
theta	0.379	0.000					0.368	0.000	0.381	0.000	0.398	0.000	0.376	0.000				
LR chi2	14896.111		48.673		81.835		15031.435		14904.236		14721.668		14894.240		49.373		88.934	
Prob>chi2	0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000	
Subjects	15485		15485		15485		15485								15485		15485	
Deaths	997		703		294		997								703		294	
Competing			294		703										294		703	

HR = Hazard Ratio, rc =reference category, Person-years at risk: 96952

Table 4 and Figure 5 show the results from the separate models for children to small and medium-scaled farmers (note: Figure 5 shows only the effects from the soil type and parish variables). A relatively strong effect of soil types and taxation value on mortality is revealed, which is consistent across the models[4]. Thus, the results indicate an effect of nutrition, through soil type and taxation value, on the mortality of the farmers' children. Moreover, no significant mortality differences are observed between the parishes for this group of children. However, in the cause-specific model for non-airborne/unspecified diseases (Model 5b), children residing in Halmstad and Sireköpinge show higher hazards of death.

Overall, children residing in areas with very high proportions of clayey till (75-100% coverage) experience a lower risk of dying compared to children residing in areas with other soil types. In particular, children residing in property units with a spatial coverage of 50-75% clayey till or with mixed soils, have approximately twice as high hazard of death as children residing in property units with a spatial coverage of 75-100% clayey till (Model 3-4). The magnitude of the effects, as well as the statistical significance, of the soil types decreases in the model that considers as outcome mortality from non-airborne/unspecified diseases (Model 5b), although the pattern of the effects remain constant. An exception is the effects of the group sandy soils 50-100%, for which the effect becomes stronger and statistical significant. That is, the hazard of death from non-airborne/unspecified diseases for children residing in farms with soil type sandy soils 50-100% is 109% higher relative to children residing in farms with soil type clayey till 75-100%.

[4] Although area was not included in the models because of its correlation with taxation value, as a sensitivity analysis, we estimated models that included area instead of taxation value, as well as models including both variables. Models including population density were also estimated. In all of these models, the effect of soil type remains.



***: p ≤ 0.001, **: p ≤ 0.01, *: p ≤ 0.05, #: p ≤ 0.1

Figure 5: Impact of soil type and parish on child mortality in Scania 1850-1914. Small and medium-scaled farmers, aged 1-15. The estimates are taken from the models in Table 4. Note that the hazard ratios and their 95% confidence intervals (the bars) are plotted on a log scale. The asterisks and hashes on top of the bars denote the significance values.

Table 4: Impact of soil type and other factors on child mortality in Scania 1850-1914. Small and medium-scaled farmers, aged 1-15.

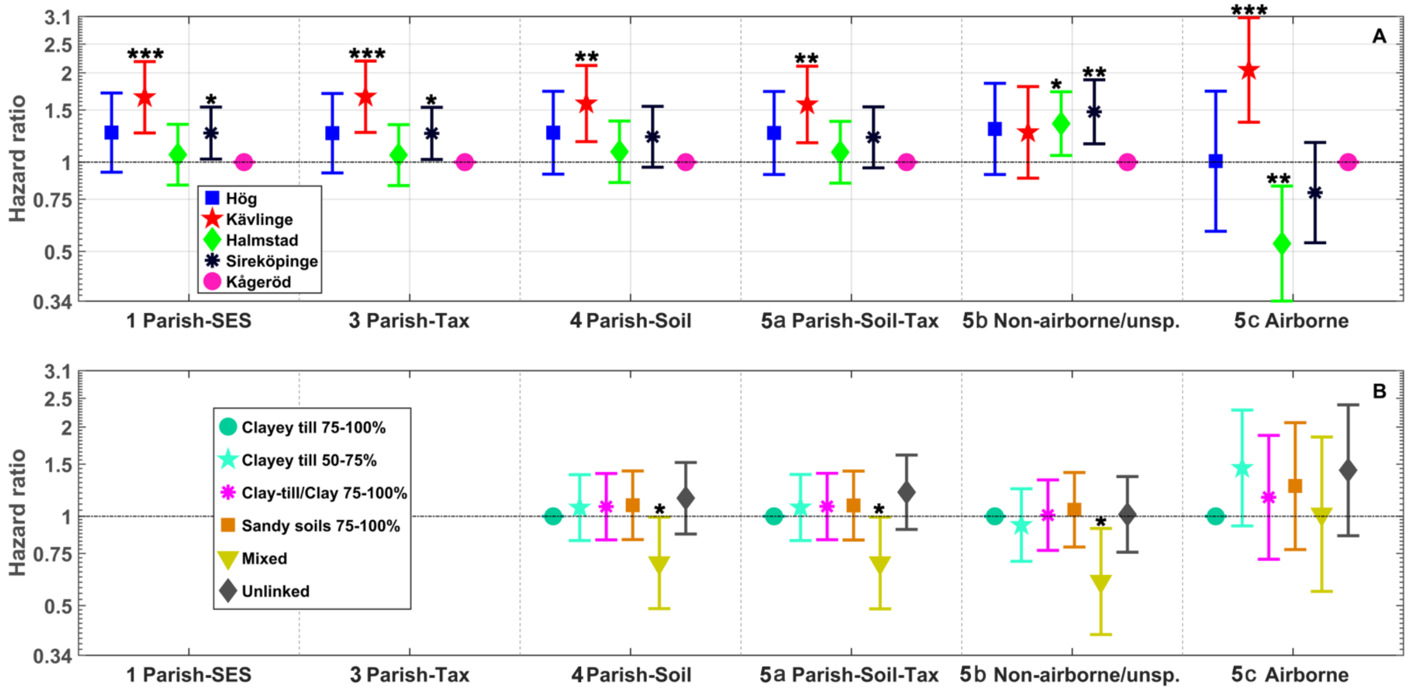
	1 Parish-SES		**3 Parish - Tax**		**4 Parish - Soil**		**5 Parish Soil Tax**			
	All-causes		**All-causes**		**All-causes**		**a All-causes**		**b Non-airborne /unspecified**	
	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish										
Hög	0.868	0.606	0.787	0.388	0.861	0.597	0.771	0.364	0.959	0.897
Kävlinge	0.932	0.823	0.843	0.591	1.006	0.987	0.888	0.735	1.043	0.920
Halmstad	1.132	0.596	1.005	0.984	1.047	0.851	0.935	0.789	1.753	0.036
Sireköpinge	1.118	0.634	0.964	0.881	1.129	0.637	0.970	0.907	1.664	0.070
Kågeröd	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc
Taxation value			0.181	0.049			0.158	0.035	0.232	0.109
Soil type										
Clayey till 75-100%					1.000	rc	1.000	rc	1.000	rc
Clayey till 50-75%					1.911	0.009	1.977	0.005	1.670	0.044
Clay-till/Clay 75-100%					1.322	0.303	1.390	0.220	1.142	0.638
Sandy soils 75-100%					1.494	0.179	1.628	0.103	1.960	0.037
Mixed					2.112	0.011	2.110	0.011	1.573	0.143
Unlinked										
Birth year	0.987	0.004	0.986	0.002	0.987	0.003	0.985	0.001	0.984	0.002
Sex										
Female	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc
Male	1.277	0.091	1.279	0.089	1.285	0.083	1.288	0.080	1.206	0.261
theta	0.707	0.000	0.645	0.000	0.611	0.000	0.539	0.000		
LR chi2	2855.502		2926.655		2906.054		2989.271		29.337	
Prob>chi2	0.000		0.000		0.000		0.000		0.002	
Subjects					3235				3235	
Deaths					207				146	
Competing									61	
Person-years at risk					20485				20485	

HR = Hazard Ratio, rc =reference category

While the effect of the taxation value on mortality may seem relatively large, it represents the increase of 1 *mantal*, which is a large unit increase (the small -and medium-scaled farmers have a *mantal* between 0.15-0.4). An increase of 0.1 of a *mantal* decreases the mortality risk by 8.4% (Model 4). Moreover, male children had a higher mortality risk compared to female children (e.g., 28.8% in Model 4) (*P<0.1*), and the shared frailty within the households was high: 53.9% in the model including soil type and taxation value (Model 4). Finally, there were no indications of serious violations against the proportional hazards assumptions for the independent variables of interest.

For the labourers' children, no significant mortality differences between the soil type groups representing areas covered by high proportions of a specific soil type are observed (Figure 6, Table 5). Besides, no beneficial effect of taxation value is found. However, labourers' children residing in areas with mixed soils (foremost a mix of clayey till, clay/clay-till and sandy soils) experience in general a lower risk of dying compared to children residing in areas with other soil type groups.

Moreover, the mortality differences observed in Figure 6 and Table 5 between the parishes for the labourers' children (Model 1a) are similar to the ones found in Table 3. This adheres both to the parish differences found for all-cause mortality as well as the large differences between the cause-specific models estimated for non-airborne/unspecified and airborne diseases. Note, however, that when including the soil type variable in the models considering all-cause mortality, there are no longer any statistical significant effects from Sireköpinge parish. Moreover, even though the urban area of Kävlinge was excluded in the analyses, children living in Kävlinge parish have a significantly higher mortality compared to the reference category in all models, except for the cause-specific model for non-airborne/unspecified diseases. This indicates that children also living outside the urban area in Kävlinge have an increased hazard of death from airborne diseases. Finally, the shared frailty within the households was generally smaller compared to the farmers' children: between 33.6% and 38.4% (Table 5: Model 1a, 3-4, 5a). There were no indications of serious violations against the proportional hazards assumptions for the independent variables of interest.



***: p ≤ 0.001, **: p ≤ 0.01, *: p ≤ 0.05, #: p ≤ 0.1

Figure 6: Impact of soil type and parish on child mortality in Scania 1850-1914. Labourers, aged 1-15. The estimates are taken from the models in Table 5. Note that the hazard ratios and their 95% confidence intervals (the bars) are plotted on a log scale. The asterisks and hashes on top of the bars denote the significance values.

Table 5: Impact of soil type and other factors on child mortality in Scania 1850-1914. Labourers, aged 1-15.

	1 Parish-SES		**3 Parish - Tax**		**4 Parish - Soil**		**5 Parish – Soil - Tax**					
	All-causes		**All-causes**		**All-causes**		**a All-causes**		**b Non airborne/ unspecified**		**c Airborne**	
	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z	HR	P>z
Parish												
Hög	1.258	0.144	1.253	0.152	1.257	0.164	1.255	0.168	1.295	0.152	1.008	0.978
Kävlinge	1.655	0.000	1.663	0.000	1.577	0.003	1.566	0.003	1.261	0.201	2.047	0.001
Halmstad	1.060	0.627	1.057	0.647	1.084	0.507	1.080	0.527	1.349	0.017	0.532	0.006
Sireköpinge	1.253	0.028	1.250	0.030	1.218	0.102	1.213	0.111	1.478	0.002	0.789	0.234
Kågeröd	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc
Taxation value			1.152	0.395			1.235	0.230	0.908	0.549	1.773	0.084
Soil type												
Clayey till 75-100%					1.000	rc	1.000	rc	1.000	rc	1.000	rc
Clayey till 50-75%					1.070	0.605	1.071	0.600	0.935	0.638	1.456	0.102
Clay-till/Clay 75-100%					1.078	0.565	1.080	0.560	1.009	0.947	1.159	0.547
Sandy soils 75-100%					1.090	0.528	1.088	0.537	1.053	0.728	1.265	0.350
Mixed					0.697	0.046	0.696	0.046	0.603	0.016	1.017	0.956
Unlinked					1.151	0.320	1.206	0.203	1.015	0.919	1.430	0.167
Birth year	0.990	0.000	0.990	0.000	0.990	0.000	0.990	0.000	0.992	0.000	0.983	0.084
Sex												
Female	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc	1.000	rc
Male	0.989	0.883	0.989	0.885	0.992	0.909	0.992	0.919	0.965	0.684	0.998	0.987
theta	0.338	0.000	0.345	0.000	0.335	0.000	0,348	0,000				
LR chi2	11255.678		11240.971		11201.692		11155.587		33.649		66.747	
Prob>chi2	0.000		0.000		0.000		0.000		0.001		0.000	
Subjects	12900								12900		12900	
Deaths	744								523		221	
Competing									221		523	
Person-years at risk	69782								69782		69782	

HR = Hazard Ratio, rc =reference category

As a sensitivity analysis, we also included possible measures of disease indicators for the labourers' children: population density, area, and whether they resided in large satellite units or demesnes (results not shown). No significant effects on mortality of such variables were found. Moreover, in Table 5 the model focusing on mortality from airborne diseases (Model 5c) shows a higher risk of death for children living under areas with 50-75% clayey till (*p=0.102*). However, the magnitude and the p-value of such effect are reduced when also controlling for area and population density.

7. Discussion and conclusions

To our knowledge this is the first longitudinal study on the micro-level that has used detailed soil type information to better understand the role of nutrition on mortality for a historical rural society. By combining detailed geographic information on residential histories with information on soil type for each property unit, we were able to analyse the impacts of soil type on child mortality (ages 1-15) for the period 1850-1914. We find that soil type primarily affected the mortality of children to farmers. Particularly, these children experienced relatively lower mortality when living in property units covered by very high proportions of clayey till. Labourers' children were also affected by soil type, but in an opposite way from the farmers' children; they had a lower mortality when residing in property units covered by mixed soils (foremost constituted of clayey till, clay-till/clay and sandy soils). This soil type, however, is the smallest category and may be heterogeneous and it may possibly correlate with other unobserved factors which have not been considered in the models. Therefore, the results show support for our first hypothesis; i.e., that soil type is a measure for nutrition and resources for children to farmers. That is, certain soil types influenced the farm-level production pattern and the quantity and quality of the output, which, in turn, affected the nutritional level of the farmers' children and thus their likelihood of dying. Moreover, we found no support for our second hypothesis, which predicted that soil was instead a measure of exposure to virulent diseases, because soil types did not affect the mortality of the two groups equally. Consequently, for the farmers' children, the results indicate a relatively important role of nutrition as a mortality predictor, which is in line with previous research on the link between nutrition and mortality in pre-industrial societies (e.g., McKeown, 1976; Fogel 1994; 2004; Puleston and Tuljapurkar, 2008; Floud et al., 2011).

Moreover, we expected that by studying the effect of soil type on mortality we could bring new knowledge on the role of nutrition with regards to the previously found geographic differences on child mortality that related to the parish of residence (Bengtsson, 2004; Bengtsson and Dribe, 2010). When estimating separate models by socioeconomic status, such geographic differences were, however, only observed for the labourers' children, and they were present also after including soil types in the models. For these children, the parish differences in the risk of death from non-airborne/unspecified diseases were strikingly different from the parish differences in the risk of death from airborne infectious diseases. Thus, the results indicate that for the labourers' children there are likely other unobserved factors that were not considered in this study that could explain some of the geographic mortality differences and further research is required for this group.

We do not know the exact reasons to the different effects of soil on mortality for the farmers' children. A possible explanation is that clayey till was in general more fertile than sandy soils and more manageable than heavy clay-till and clay soils. The suitability of a soil type for agriculture was also likely affected by the market and the technological developments. Because some soils may have been more suited for some specific crops, their suitability were therefore likely influenced by the current market demand for these crops. For example, the rising popularity of new crops such as the sugar beets, which began to be cultivated in the 1890s in the five parishes (BiSOS, 1892), as well as the increased use of both natural and artificial fertilizers (Morell, 2011) probably influenced the importance of some soil types. For example, well drained medium to slightly fine-textured soils are good soils for sugar beets (FAO, 2015). Hence, lands with large proportions of clayey tills and, possibly, clay-tills may have been suited for such crops. However, sugar beets are also sensitive to the pH value in the soil which may vary across areas regardless of the soil (FAO, 2015). To better study the impact of the technological developments, the analysis could have been divided into two periods; however, this was not possible because it resulted in an insufficient sample size. Lastly, the shared frailty component, which measures unobserved characteristics within the household-level, was high in the models estimated for the farmers' children (54%). This suggests that their mortality is affected also by other unobserved factors which has not been considered in this study.

For the labourers' children it remains an open question why those residing in property units with mixed soils experienced lower mortality, even if, as stated earlier, this soil type is the smallest category and may be heterogeneous. Although no effects of soil type on mortality from only airborne infectious diseases were found, certain soil types may influence the exposure to other diseases; e.g., by creating beneficial conditions for habitats containing mosquitos transmitting malaria (Leonardo et al., 2005). There can also be direct effects of soil, such as the presence of pathogens, or that certain trace elements or heavy metals correlate with specific soil types which are transferred to the food cultivated in it. However, if this was the case, we would expect to also find mortality differences between some of the soil type groups containing high proportions of clayey till, clay-till/clay or sandy soils, because the mixed soil type group is foremost constituted by those soil types. Moreover, if mixed soils were beneficial for agriculture, we would also expect to find a beneficial effect of mixed soil types for the farmers' children, which we do not find. Therefore, a possible explanation is that the mixed soil type group correlate with other unobserved factors which have not been considered in the models. This study makes, however, no attempts to draw conclusions on the causal mechanisms and further research is therefore needed to better understand such mechanisms as well as how they may have changed through time.

Moreover, the fertility of the soil as well as the animal force and tools used on the farm likely affected the human workforce needed to cultivate the land. In addition to influencing the agricultural productivity, such factors likely affected the level of human contact and thus the exposure to virulent diseases. These factors may also correlate with the socioeconomic status (e.g., the economic ability to own animal force). Therefore, if soil type was a measure of exposure to virulent diseases, it may not necessarily affect the mortality of all social groups equally, as stated in the second hypothesis. Additionally, at farms with livestock production, parts of the agricultural output would likely be directed for animal feeding which may have affected the diet of the people living at the farm. Lastly, the presence of livestock can also reduce the exposure (inside the living areas) to some mosquito species transmitting malaria (Mayagaya et al., 2015). Thus, by including farm-level information on animal workforce in the models, we would be able to better study the abovementioned relationships. However, this has not been possible because of the lack of farm-level data on livestock.

Some research indicates that soil affects infant mortality; e.g., Munro et al. (1997) found that wards dominated by wet soils had a relatively high infant mortality. In contrast, no effect of soil types on mortality was found for infants in the models that we conducted as a sensitivity analysis. However, both the demographic and geographic data used in the study by Munro et al. (1997) were on an aggregated level, whereas this study uses longitudinal micro-level data over a smaller area. Furthermore, we did not classify the soils based on their wetness; therefore, the results may not be comparable.

Although this work brings new knowledge to our understanding of mortality in the past, it is not free from limitations. One such limitation concerns the individuals that for parts of or for their whole life-course have not been linked to a property unit. Many of the poorest families belonged to this group, families with no fixed addresses and who often resided in poorhouses. They were a vulnerable group with relatively high mortality (Table 3). Such individuals are important to consider in the analyses to avoid creating a potential risk of a bias in the results. Including them as a separate group (Unlinked) in the soil type variable has been one way to handle this problem. However, this was only possible to do in the less extended models for the labourers' children.

Another limitation is the correlation that exists between some of the soil type groups and parishes (see e.g., Figures 2-3) and, in some degree, between soil type and SES. Thus, there is some redundancy between the variables. The multicollinearity tests, however, showed no serious indications of such concerns; therefore, the variables likely explain different parts of the variations in mortality in the model. Connected to this issue is also the spatial autocorrelation of the soil types. To overcome such limitation, we estimated models that included a frailty component for a geographical unit; i.e., the property units (not shown in this paper). This did not change our main results in any substantial way. However, a more proper way to study this would be to use a model that also takes into account the neighbouring areas and thus controls for the spatial autocorrelation. For example, a Cox proportional hazard model with spatially shared frailties (Darmofal, 2009).

A third limitation regards the quality of the soil type variable. The positional accuracy of the soil type data is between 50 to 75 metres, and the absolute positional accuracy of the digitized property units is approximately 25 metres (i.e., the average distance between a point in the dataset and its corresponding point in the true world). Moreover, some individuals that owned several property units were only linked to the property unit in which they lived, which means that the soil type and property unit area measures do not represent the size of the total land for these individuals. Thus, these uncertainties may introduce biases and errors in the models used in this study, e.g., by over-estimating or under-estimating the effects on mortality from soil, especially if the errors are non-random (see e.g., Zandbergen, 2007; Pantazatou et al., Forthcoming). Therefore, in future studies it is important to study the propagation of the uncertainty and how it may affect the results.

Finally, the models on cause specific mortality were limited by the large share of unspecified deaths and also by the fact that the two groups considered, non-airborne/unspecified and airborne, may not necessarily represent a proper distinction between causes of death that may and may not be related to nutrition. However, we see these estimations as a first and preliminary step to better understanding the role of nutrition on mortality and further research that looks more in-depth into different causes of death is required.

The findings of this work could be extended by conducting further studies and making some additional improvements to the models. Foremost it is possible to use various soil assessment models or crop yield models to more accurately estimate the farm-level productivity (Brunt, 2004). For our study area, we can obtain historical information about annual temperature and rainfall, as well as modern elevation data on 2 meter resolution. Parish-level information about agricultural production is also available for most of the study period, which can be used to estimate crops that increase nitrogen and humus in the soil. Finally, with the use of elevation data, it is also possible to compute the amount of sunlight that each field is exposed to, and topographic wetness indexes (TWI) to estimate the wetness of each soil. Lastly, by digitizing the forest lands of the property units (foremost in Kågeröd parish) we could consider such additional resources from forestry in the models. Future studies could also take into account population density, road networks and distance to wetlands as possible indicators of transmission of diseases and asses their impact on mortality in comparison to soil type.

It should also be noted that although the focus of this paper has been on better nutritional status due to better farm-level productivity, it may also be important to consider other possible effects of income, such as better housing conditions, which could influence the mortality of children.

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Appendix 1: Explanatory variables used for sensitivity tests

This Appendix describes the explanatory variables used for various sensitivity tests, but which were not included in the results tables.

Land type – A categorical variable indicating whether the family lived on freehold/crown or manorial land. This variable can be used together with the taxation value as an alternative SES.

Property unit area – A continuous variable in hectare, which can be used as an alternative measure of wealth. We expect that property units with large areas are beneficial in general; on the other hand, large areas with poor soil could require harder work and energy than smaller farms with fertile soil. Hence, hard work combined with malnutrition may increase the mortality (Floud et al., 2011). It should be noted that several property units in Kågeröd included forests, but we lack information on those areas.

Satellite units/Demesnes - One problem with the property unit area is the presence of large commercial farms, called satellite units (Swedish: Plattgård) (cf. Lundh and Olsson (2011)), and large demesnes. On such lands, mostly landless individuals such as crofters and other agricultural workers lived and worked. Thus, the area variable may be misrepresentative because the largest property units in the study area were all satellite units or demesnes. Therefore, we create a variable indicating whether individuals worked on such land or not.

Population density – Considered as an indicator of exposure to diseases. We define a categorical variable indicating whether the individuals were living in a property unit with a population density above or below the median value (73.45 individuals/km^2). We create the variable based on a simple measure of population density in which the annual number of individuals within each property unit is divided by the property unit area.

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