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Factors controlling the spatial specification of phosphorus in agricultural soils

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1. Introduction

Phosphorus (P) is one of the most intensively studied nutrients due to its particular and peculiar role in agro-ecosystems. As a key component in ribonucleic acid and because of its function in energy transfers via adenosine triphosphate, P is essential for all plant growth. Its low natural concentration and low solubility in the soil, makes it commonly a key growth-limiting nutrient in soils and waters (Sharpley et al., 1998). In animal producing areas such as Western Europe, USA, Canada and Australia an over-supply of agricultural P leads to impaired water quality due to the proliferation of hazardous algae blooms and undesirable aquatic weeds (Bach and Frede, 1998; Correl, 1998; Haygarth and Jarvis, 1999). On the other hand in developing countries P-deficiency hampers the development of the agricultural sector (Breman, 1990; van der Pol, 1992; Stoorvogel and Smaling, 1990; Runge-Metzger, 1995; Uebel, 2000).

Although, estimates of world phosphate reserves and the availability of exploitable deposits vary greatly, it is commonly recognised that high quality reserves are being depleted rapidly and that the prevailing management of phosphate, a finite non-renewable resource, is not fully in accordance with the principles of sustainability (Steen, 1998). The key to sustainable P utilisation is the concept of balanced fertilisation (Tunney, 1990), whereby the fertiliser rate is calculated from the balance between the natural supply by soil and environment, the nutrient demand of the crop and inevitable losses to the environment (Vermeulen et al., 1998). The two major obstacles to meet this ideal case are firstly, the accuracy of the methods employed to quantify both, the background P concentration in the soil and the demand by the crop and secondly, the spatial variability of soil fertility parameters (Haneklaus and Schnug, 2002).

The estimation of the phosphorus demand of crops based on the background P concentration in the soil is not a straightforward task. It has long been recognised that the biological availability of a nutrient depends not simply on its concentration but, critically, on the chemical form in which it occurs in the soil system (Ure and Davidson, 1995). In this sense it is important to distinguish between the geochemically available and the biologically relevant or bioavailable fraction of the total nutrient concentration in the soil environment. The mobile or geochemically available fraction can be defined as the fraction of a nutrient that materially participates in either phase distribution or physical transport processes over time and spatial scales of interest (Wolt, 1994) and the biological fraction is the fraction of the total quantity that is or has been available to an organism.

The availability of a nutrient is governed by two factors: its chemical speciation and its mobility which is a function, *but not exclusively of* the former. P is absorbed by plant roots as orthophosphate either in the $H_2PO_4^-$ or HPO_4^{2-} form (Barber, 1980). The soil parent material is the sole source of P for plant growth unless fertilisers or manure are applied. Few unfertilised soils release plant available P at rates sufficient to meet P requirements for continuous crop production, and P is commonly deficient (Sanchez and Uehara, 1980). Exceptions are younger soils formed from alluvium, glacial till and basic volcanic rocks of high P content (Wild, 1988). Even these soils may require periods of fallowing or flooding and puddling (e.g. lowland rice) to increase P availability to crops (Hedley et al., 1995).

Although the fate of phosphorus when applied to soil remains something of an enigma (Fey 1988), it is widely accepted that more than 80 % is immobilised by the soil due to precipitation and sorption processes (Sample et al., 1980), whereby the limiting step to furnish crop requirements is the dissolution of initial reaction products during the cropping season. P is present in the solid phase of soils not in the form of definite and easily separated species, but forms a continuum of compounds of different composition and solubility (Simonis, 1996). In practical terms, the P soil continuum is thought of as pools, that are in equilibrium with each other, whereby each pool consists of P species with a similar solubility. This heterogeneous equilibrium is constantly disturbed by fertiliser input, the uptake by the growing plant and by physical, chemical, or biochemical changes in the soil (Fig. 1.1).

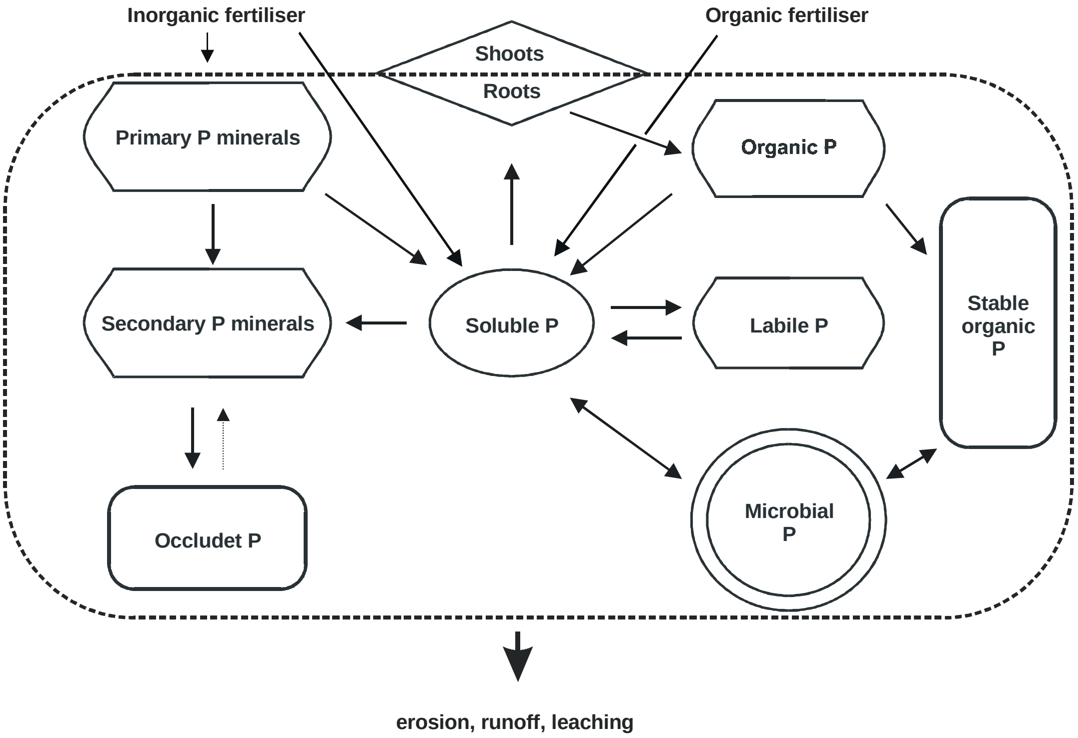

Fig. 1.1: The soil P cycle (adapted from Steward and McKercher, 1982).

Soil testing for P is a well- established agricultural practice, recognised world-wide as a cost-effective means to identify crop P requirements (Olsen and Sommers, 1982; Fixen and Groove, 1990). The objectives of soil tests for P are firstly to group soils into classes for the purpose of making fertiliser recommendations, secondly to predict the probability of getting profitable responses to application of fertiliser P and thirdly to provide an index of the amount of P a soil can supply (Kamprath and Watson, 1980). Numerous studies have conducted elaborate soil test methods to predict P availability to crops and algae (Watanabe and Olsen, 1965; Van der Paauw, 1971; Sibbesen, 1978; Hedley, et al., 1982; Barrow, 1983; van der Zee, et al., 1987; Morel et al., 2000). It is beyond the scope of this work to discuss the advantages and disadvantages of different methods. However, the overall limitation of soil P tests as a tool for predicting P dynamics is that information gained from soil testing is discreet in time and space, and as such soil P tests do not mirror dynamic processes, but reflect purely a singular steady state event. For a balanced fertilisation it is necessary to quantify not only the instantly plant-available P fraction, but also P which can be released from soil resources during the growth period of the crop (Van Noordwijk et al., 1990).

Furthermore, soil sampling is usually aimed at presenting the average nutrient concentration of the field under investigation, without taking the spatial variability of soil fertility parameters into account. As the variability of soil parameters within a single field can easily be as high as the variability of the same parameter within the surrounding landscape (Schnug et al., 1993), using the average nutrient concentration of a soil for fertiliser recommendations leads to spatial over-supply and under-supply of the soil and consequently to an imbalanced fertilisation (Schnug, 1996a). These shortcomings of conventional fertiliser practices led to the development of the Site-Specific Nutrient Management (SSNM), which aims at transferring the site-specific nutrient demand into variable fertiliser rates which depend on the spatial variability of soil and crop parameters (Haneklaus and Schnug, 2002). SSNM usually operates with digital agro-resource maps (DARMs) which are processed in geographical information systems (GIS) (Schroeder et al., 1997). To embrace the entire variation of the field in order to obtain a ‘true’ chemical image a high sampling density is needed, which in most cases is not economically feasible or sustainable for farmers (Lowenberg-DeBour and Boehlje, 1996). In order to develop economically sound sampling strategies as well as utilising ancillary data sources, it essential to understand the spatial and temporal behaviour of nutrients within the soil.

While the temporal dynamics of soil P have received a lot of research attention, and based on long term field studies a substantial amount of information is available about the transformation products of P fertiliser within temperate (Werner, 1969; Werner, 1971a, 1971b; Munk and Grass, 1974) as well as tropical soils (Tiessen et al., 1983; Ball-Coelho et al., 1993; Beck and Sanchez, 1994; Guo et al., 2000), very little is known about the spatial dynamics of different P pools.

Unlike C and N, which can be added to the soil system from the atmosphere, the P status of natural systems is essentially controlled by the occurrence of primary apatite minerals (Walker and Syers, 1976; Bowman et al., 1998). Consequently, the P enrichment of soils depends directly on P inputs by mineral fertilisers and manure (Marcinowski and Sapek, 1998). As a tetrahedral oxyanion phosphate has a very low solubility in soils and in general does not move with solvent fluxes, apart from small distance diffusion (Barber, 1980). In this sense P is regarded as an “immobile” nutrient. Thus, the physical movement of P is restricted to the movement of P associated with soil particles and large molecular-weight organic matter (particulated P) by either bioturbation, soil tillage activities or soil erosion during flow events (Catt, 1997; Sharpley et al*.,* 2000).

These characteristics of soil P were recognised long ago by European geographers and since then used in archaeology to trace back ancient settlements (Arrhenius, 1929; Broadbendt, 1981; Proudfoot, 1976). Conway (1983) introduced the use of total P distribution patterns for the analysis of small-scale occupation deposits. For example, one building showed evidence of having been demolished and partially reincorporated into the courtyard of a subsequent structure. The floor area of the remnant original structure was protected by a layer of small stones and contained high levels of P. That portion of the floor which was subsequently converted into a courtyard, unprotected by stones, had less total P, having lost it by exposure and erosion. In our agricultural context this translates to the following conclusions: Firstly, as far as its total amounts are concerned, P applied with fertilisers may not move from the place it is applied to and secondly, keeping in mind that most soils are naturally poor in P nearly all the spatial distribution of total P in agricultural soils should be more or less random, reflecting only the spatial sum of distribution faults of past anthropogenic activities (e.g. fertilisation, animal husbandry). Spatial relationships may only have developed under the influence of erosion processes (Conway, 1983).

During the last ten years the study of spatial variation of soil fertility parameters has expanded considerably, but studies that investigated the spatial distribution of soil P, generally focused solely on the distribution of so-called plant available P. The results of these studies showed that plant available P does not fluctuate randomly, but shows distribution patterns with well defined lag ranges, where the ranges differ, depending on the sampling procedure and scale of investigation (Tab.1.1, for a brief introduction into geostatistical terminology see Chapter 2.6.2).

Tab. 1.1: Parameters of autocorrelation for soil P extracted by different P-methods in selected investigations.

Authors	Soil texture	Sampling design (m)	Extraction method	Variogram model	Range (m)
Trangmar, 1982	/	1.5 m *1.5 m	Truog	Spherical	5.6
Boyer et al., 1996	uL	2 m transects along slopes	Bray I	Spherical	37
Doberman et al., 1997	T	5 m triangular grid	Olsen	Nested	48
Simard et al., 2000	uT-T	12*15 triangular	Mehlich III	Exponential	139
Karlen et al., 1997	/	15*15 grid	Bray I	Spherical	70
Webster & McBratney, 1987	/	16*16 random	Morgan	Spherical	241
Rühling, 1999	lS	18*18 grid	$CaCl_2$	Spherical	94
Gupta et al., 1997	sT	20*20 grid	Mehlich I	Exponential	29
Romanokov, 1997	uL	20*20 grid	0.2N HCl	Spherical	50-60
Nolin et al., 1996	uT-T	30*30 grid	Mehlich III	Exponential	39
Haneklaus et al., 1997	lS-sL	30*30 grid	CAL	Spherical	153
Haneklaus et al., 1997	sL-uL	50*50 grid	DL	Spherical	115
Haneklaus et al., 1997	lS-sL	50*50 grid	DL	Spherical	131
Chien et al., 1997	sL-uL	250*250 grid	Mehlich III	Spherical	580
Yost et al., 1982	/	1-2 km transect	Olsen	Exponential	1000

Additionally, it has been shown that the distribution of available P does not necessarily resemble the distribution of total P. When investigating the relationship between total P and plant available P in an agricultural soil Strohbach (1986) found that the correlation between the two was not the same throughout the field. Jentsch (1986) and Nowack (1990) demonstrated that the correlation between total P and plant-available P in soil was strongly dependent on the parent material. From this reports it appears that the speciation of soil P is dependent on site specific factors and as such is a spatial process. In this sense "spatial speciation" is defined as the chemical reactivity of a nutrient with site specific environmental factors, and the subsequent formation of geochemical species that display different spatial dependencies (Gassner et al., 2002a).

The question, therefore, arises as to what causes the spatial speciation of agricultural P? The speciation is dependent on chemical (precipitation-dissolution, adsorption-desorption), biological (immobilisation- mineralisation) and physical (temperature, moisture) factors. Within fields and across short distances, these factors can vary significantly in well-defined patterns, whereby the distribution is the result of superimposed environmental processes acting at different spatial scales and over different time periods (Goovaerts, 1992; Castrignanò et al., 2000). Insight into the environmental processes that result in the spatial speciation of soil P and as such govern the behaviour of applied fertiliser are necessary to predict the interconversion and equilibrium distribution of different soil P pools under specific conditions such as geomorphology, field management and soil types.

Spatial phenomena are usually detected, modelled and estimated by means of geostatistical methods which explore correlation between neighbouring data (Goovaerts, 1997). Geostatistics, originally used in the mining industry (Matheron, 1971), is a branch of applied statistics that provides a quantitative measure of the intuitive sense that points which are closer together are more related than points farther apart. The underlying assumption is that the phenomena studied, e.g. the distribution of soil P concentrations (regionalised variable), is the outcome of an unknown environmental process (random function). The study of multivariate problems, where several variables and their spatial interdependence are investigated (e.g. different P species) is based on the assumption that all regionalised variables being studied are generated by the same set of environmental processes (Wackernagel, 1998; Goulard and Voltz, 1992; Goovaerts, 1992). Geostatistical techniques include variography (Isaaks and Srivastava, 1989), which is one way of modelling the random function and kriging (Krige, 1951), which provides estimates of the regionalised variable for unsampled locations.

The principal hypothesis of this research work was that the distribution of functional soil P pools within the agroecosystem is not random, but displays an autocorrelation function that can be estimated using geostatistical methods.

The main objectives of the research work presented here were:

I. To select phosphorus extraction methods that could be used to extract soil P fractions which are representative of functional soil P pools.

II. To quantitatively assess the spatial distribution of these P fractions using geostatistical methods.

III. To contrast the similarities/differences amongst these functional soil P pools and to explain the predominant environmental mechanisms which give rise to the observed statistical patterns.

IV. To investigate the feasibility of geostatistical methods to assess the suitability of different extraction methods for plant available P.

2. Material and methods

2.1 Selection and description of study sites

The variability in soil parameters displayed at a given site, at a given time, is controlled by a number of important processes. The most influential are the geological and pedological processes that define the soil type and govern the majority of static soil properties e.g. texture, and cation exchange capacity (Jenny, 1941). Additional effects on the variability of soil attributes are contributed by soil management practices and cropping systems. These are known to greatly manipulate the more dynamic soil properties such as nutrient, water, air and solute regimes (Bouma and Finke, 1993). On that account the criteria for the selection of study sites for this research work was the coverage of a wide variety of different environmental factors. Thus, is was decided to use three study sites that differ in climate, parent material, topography, P fertiliser regime and land management. A summary of the general characteristics of the selected study sites is given in Table 2.1.

Tab. 2.1: General characteristics of selected study sites in the year of sampling.

Name	Location	Size ha	Climate	Soil type	Land-use	Slope°
Kassow	Mecklenburg-Western Pomerania, Germany	78	temperate	Luvisol	Arable (Peas)	2
Warberg	Magdeburger Boerde, Germany	40	temperate	Cambisol	Arable (Sugar Beet, Winter Wheat)	3
Ceveiro	São Paulo State Brazil	2200	humid-subtropical	arenic Paleudult typic Udorthent	Arable (Sugar-cane) Forest Pasture	5

2.1.1 Geophysical description of the study sites

Kassow

Kassow (E12° 06’, N53° 10’), is located in the northeast of Germany (Fig 2.1). The landscape is characterised by flat, slightly undulating till plains of the north German young moraine area formed during the Weichselian (deglaciation ~14000 years BP). In young moraine areas a 40-60 cm thick silty coversand has developed, overlying non calcareous boulder clay. This lead to the formation of diluvial soils (albi-luvic Cambisol), whereby Cambisol developed from the sandy substrate and covers an eroded Luvisol from the boulder clay. The average depth of decalcification lies within 160-180 cm (Kuehn, 2001).

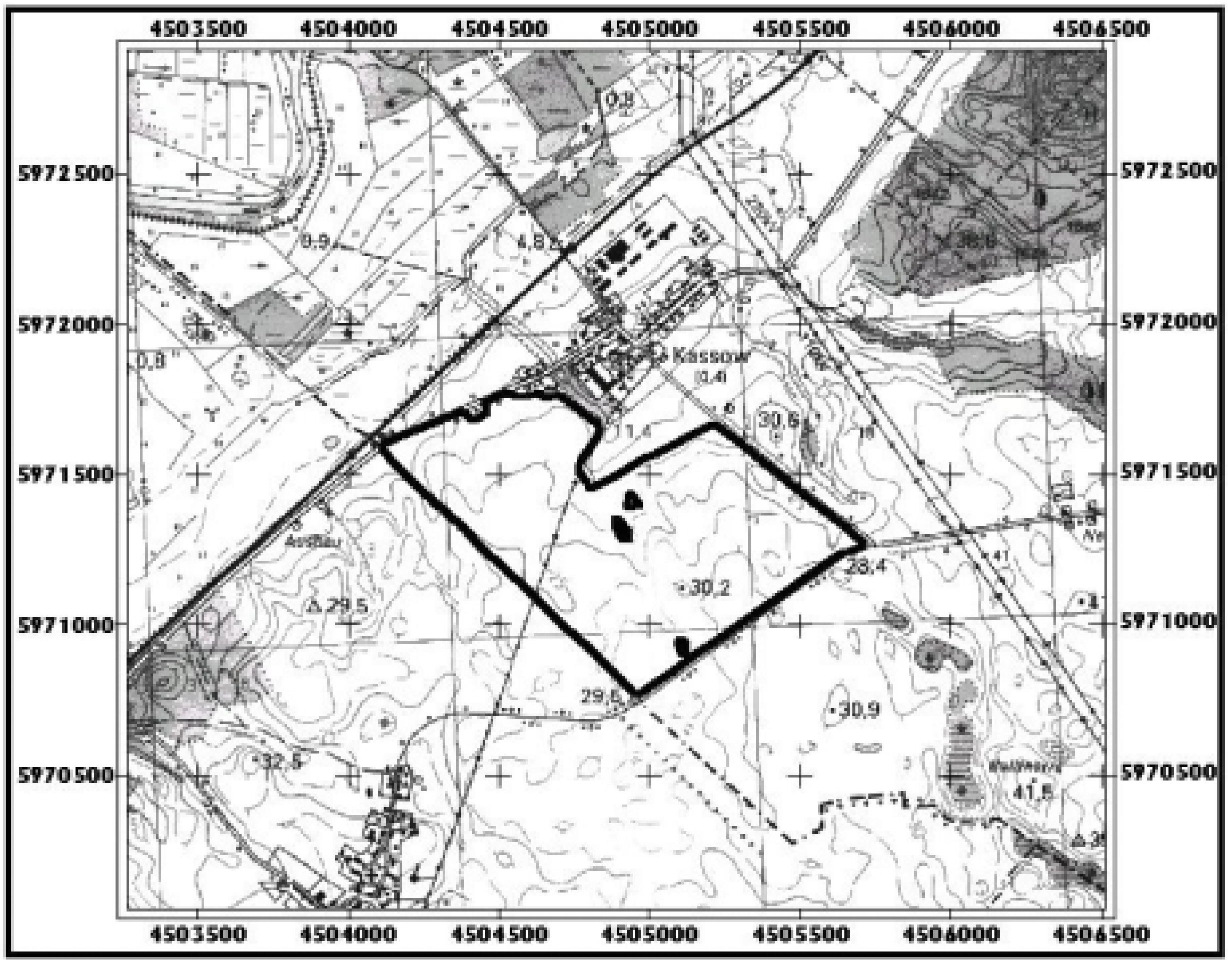

Fig. 2.1: Location of the Kassow study site (E10°54', N52°10'). Topographic map 1:25000 (LvermA-MV, 2000).

The field, under investigation, field 106, is about 78 ha in size. Elevation decreases from 32 m to 10 m towards the northwest, with an average slope of 3.5 % (Fig 2.2). Ephemeral gullies are currently manifested at the northern end of the field.

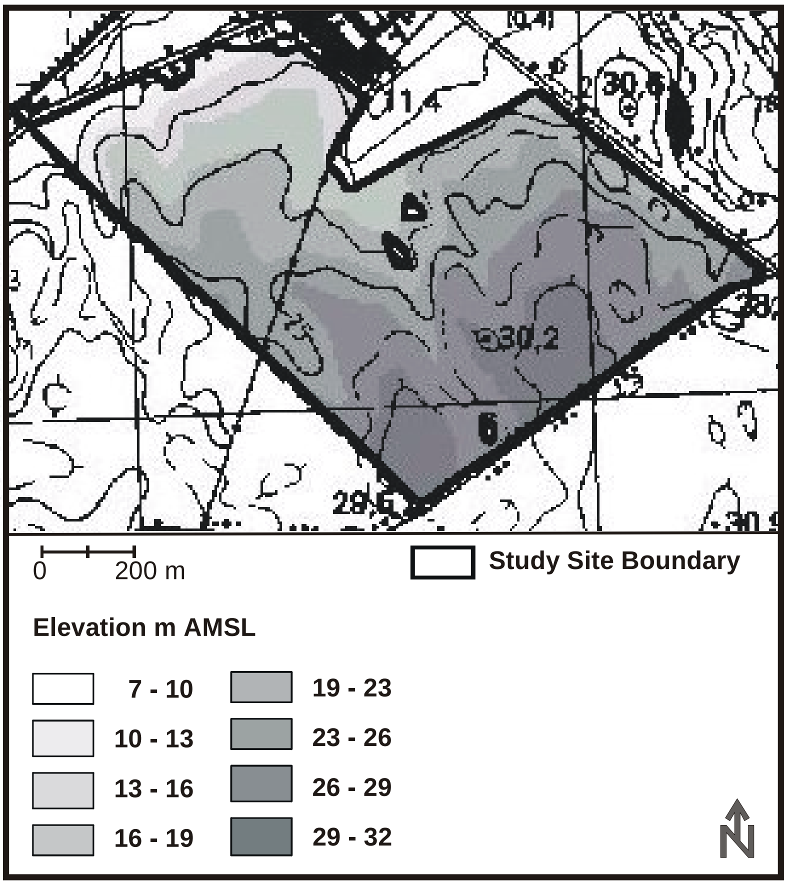

Fig. 2.2: Digital elevation model for the Kassow study site (E12° 06’, N53° 10’).

The soil texture varies mainly by its silt content, ranging from loamy sand (53 %) over medium loamy sand (13 %) and high loamy sand (27 %) to sandy loam (7 %), (Fig. 2.3). Prior to 1996 the field used to be conventionally tilled, but after a severe erosion event, which resulted in the formation of a deep (1.6 m) gully at the northern end of the field (Pic. 1), management was changed over to conservation tillage.

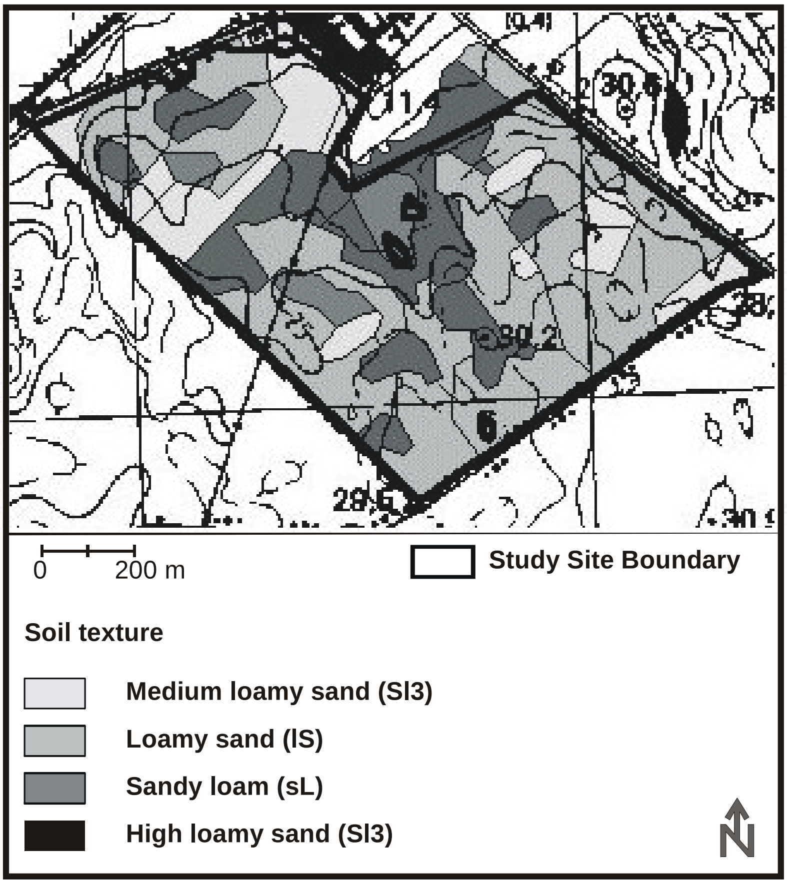

Fig. 2.3: Distribution of soil texture classes in Kassow (E12° 06’, N53° 10’).

Pic. 1:Ephemeral gully at the northern end of field 106, Kassow (E12° 06’, N53° 10’).

In 1994 and 1995 variable rate application of N, P, K and lime was carried out. The P fertilisation was based on a digital-agro-resource map for plant available soil P. P was determined by the calcium lactate method (Egner-Riehm). The map was based on a total of 30 soil samples, collected on a 200 m grid, whereby unsampled areas were estimated using inverse distance interpolation. Rates varied from 0 P_2O_5 kg·ha^{-1} to 112 P_2O_5 kg·ha^{-1} corresponding to 0 mg kg^{-1} and 60 mg kg^{-1} soil P, respectively (Fig. 2.4).

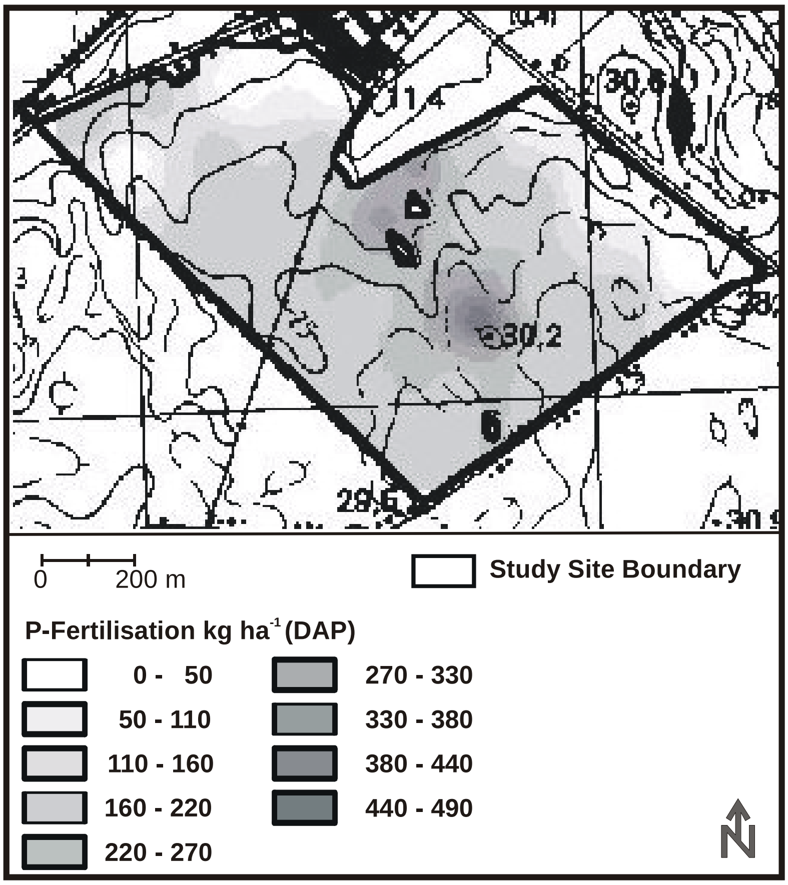

Fig. 2.4: Variable rate fertiliser application map for field 106 in Kassow (E12° 06', N53° 10').

Warberg

Warberg (E10°54', N52°10') is located on the fringe of the fertile lowlands of the Magdeburger Boerde, Germany. The Boerde is characterised by glacial aeolian loess deposits. The farm of Warberg is situated in a gently rolling landscape, whereby fields are separated through drainage channels. A subcatchment, comprising five fields, with a total area of about 40 ha was selected as a study site (Fig. 2.5).

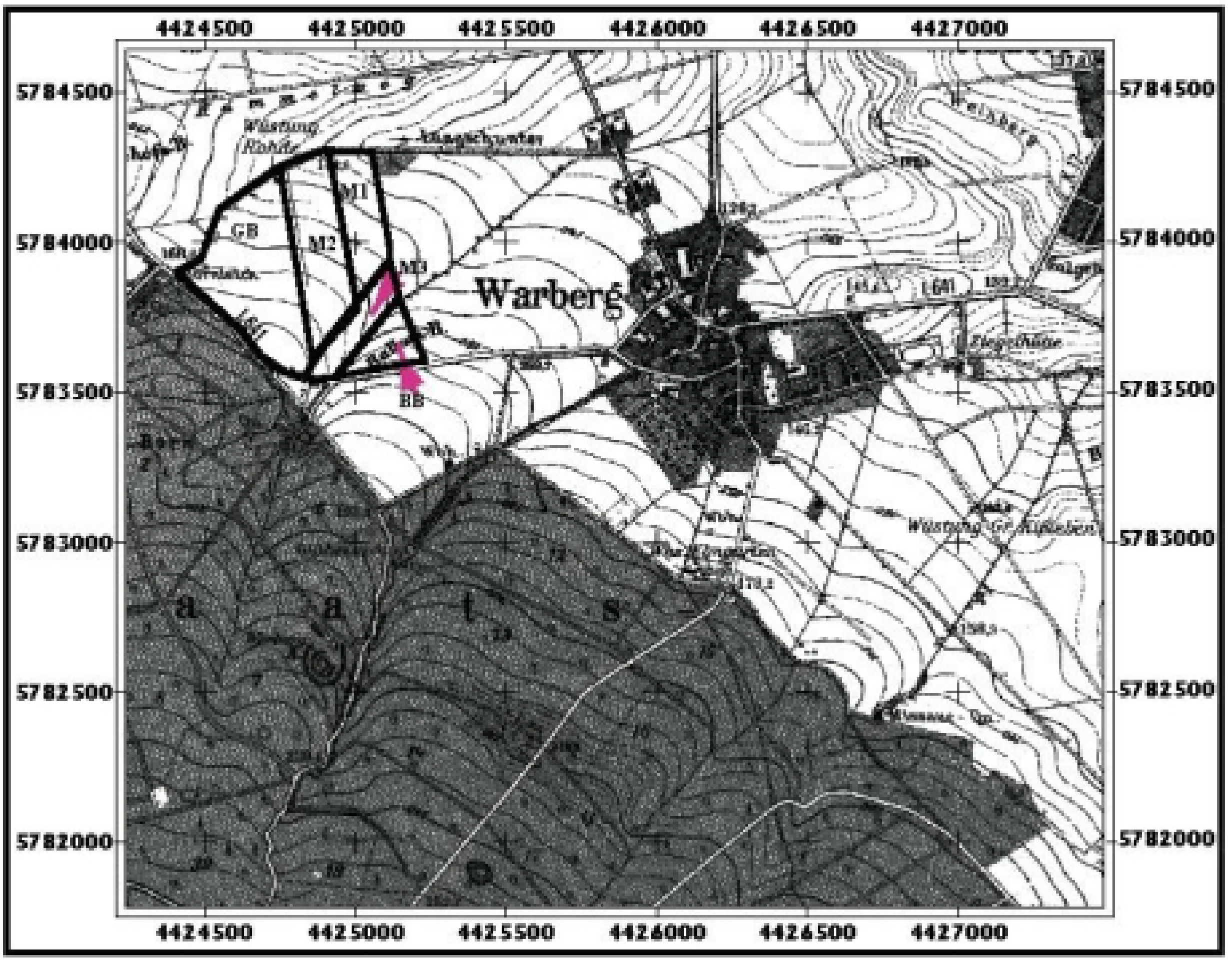

Fig. 2.5: Location of the Warberg study site (E10°54', N52°10'). Topographic map 1:25000 (NLfB, 2000).

The soil texture varies mainly by its clay content, ranging from loam (88 %) over loamy clay (11 %) to clay (1 %) (Fig. 2.6). Elevation decreases from 178 m AMSL to 141 m AMSL towards the northwest, with an average slope of 3°. The topography is complex with two perpendicular drainage lines. Greatest elevation change, accompanied by a steep slope is found in the south of the sub-catchment, whereby summit and shoulder are located on field BB and backslope and footslope position on field M3. The second more gentle, but longer slope starts from field GB, over fields M2 to field M1 (Fig. 2.7).

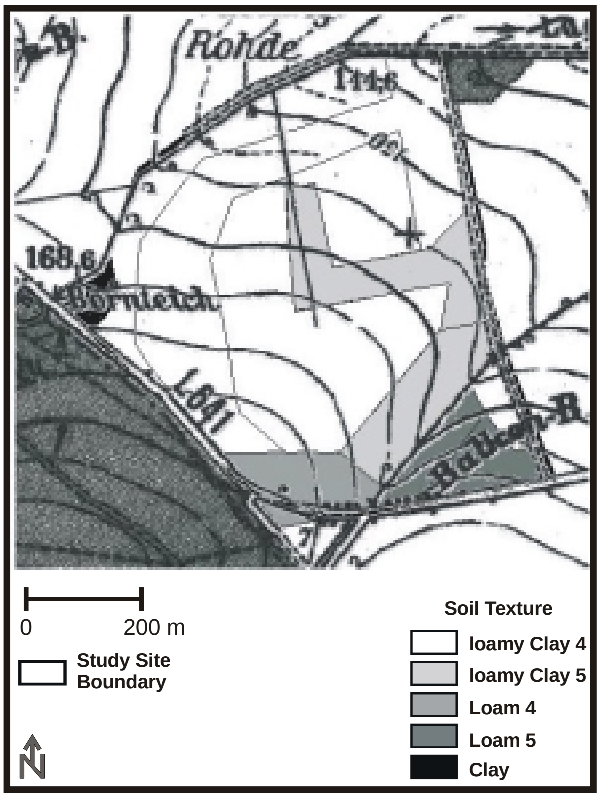

Figure 2.6: Distribution of soil texture classes in Warberg (E10°54', N52°10').

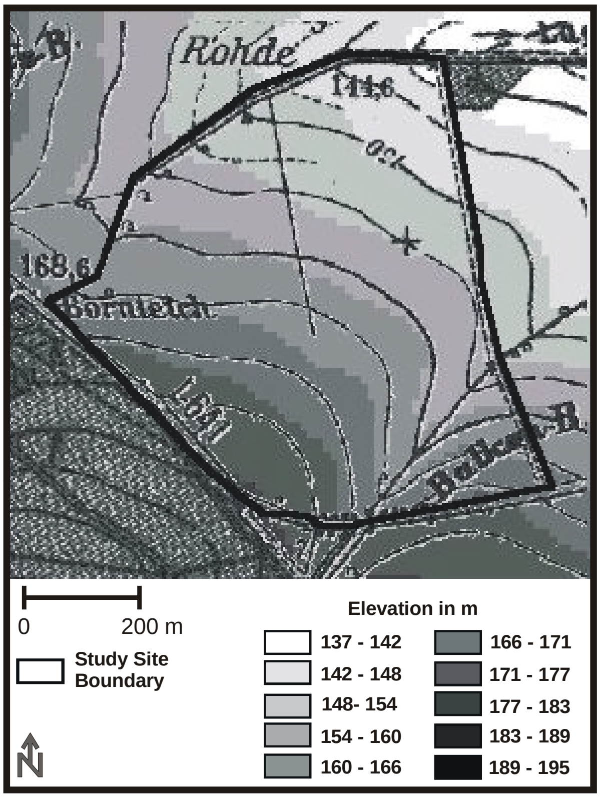

Figure 2.7: Digital elevation model for the Warberg study site (E10°54', N52°10').

The soil is a dark Luvisol (typic Hapludalf), with an average depth of about 1 m, followed by a carbonate rich C horizont. Fields BB and M3 were further characterised by carbonate accretion so called “Loesskindel” in the topsoil layer (Pic. 2). Loesskindel are formed in and around macro pores due to CO_2 partial pressure changes in the pore water (Scheffer and Schachtschabel, 2002)

Pic. 2: Loesskindel (www.geo.unizhi.ch/bodenkunde).

Management practices differ for individual fields. Conservation tillage is applied to those fields that display a larger erosion potential, whereas other fields are conventional tilled. Mineral, water soluble P fertiliser is applied every three years based on the LK Hannover (1998) fertiliser recommendation for this region. Additionally, swine manure, with an average concentration of 3.04 % P_2O_5 was irregularly applied, following the German ordinance of fertilisation (DüngeV, 1996). At the time of the study last mineral fertiliser application was applied three years prior to sampling, but recent manure application was evident on field GB. The application of swine manure does not only increase the concentration of macronutrients like N and P, but also the concentration of micronutrients, especially Cu and Zn (Jongbloed and Lenis, 1998). As no records were available of the past application history of swine manure, the total Zn concentration in the soil was, therefore, used as an indicator of organic P amendment (Tab. 2.2).

Tab. 2.2: Main physical and management characteristics for individual fields at Warberg (E10°54', N52°10') in 2000.

Field Label	**n**	**Size** **ha**	**Crop**	**Tillage practice**	**P_{CAL}** **mg kg $^{-1}$**	**Zn** **mg kg $^{-1}$**	**Slope** **°**
BB	37	3.3	Winter Wheat	Conservation tillage	37 - 185	41 – 154	3 - 7
GB	161	17.8	Winter Wheat	Conservation tillage	36 - 99	37 – 256	2 - 4
M1	66	6.0	Winter Wheat	conventional	29 - 74	36 – 93	2 - 4
M2	105	8.0	Sugar Beet	conventional	31 - 87	36 – 77	2 - 4
M3	37	3.5	Winter Wheat	conventional	39 - 84	38 - 75	2 - 6

Ceveiro

The Ceveiro watershed, a sub-catchment of the Piracicaba river basin, is located within the sugar cane growing region of São Paulo State, Southeast Brazil (W74º 47’, S22º 40’) (Fig 2.8). The climate is humid subtropical with a dry winter; less than 30 mm rain in the driest month, warmer than 22°C in the hottest month, and cooler than 18°C in the coldest month. The 2.200 ha catchment is well known for its severe soil degradation caused by erosion (Sparovek et al., 1997, Bacchi et al., 2000).

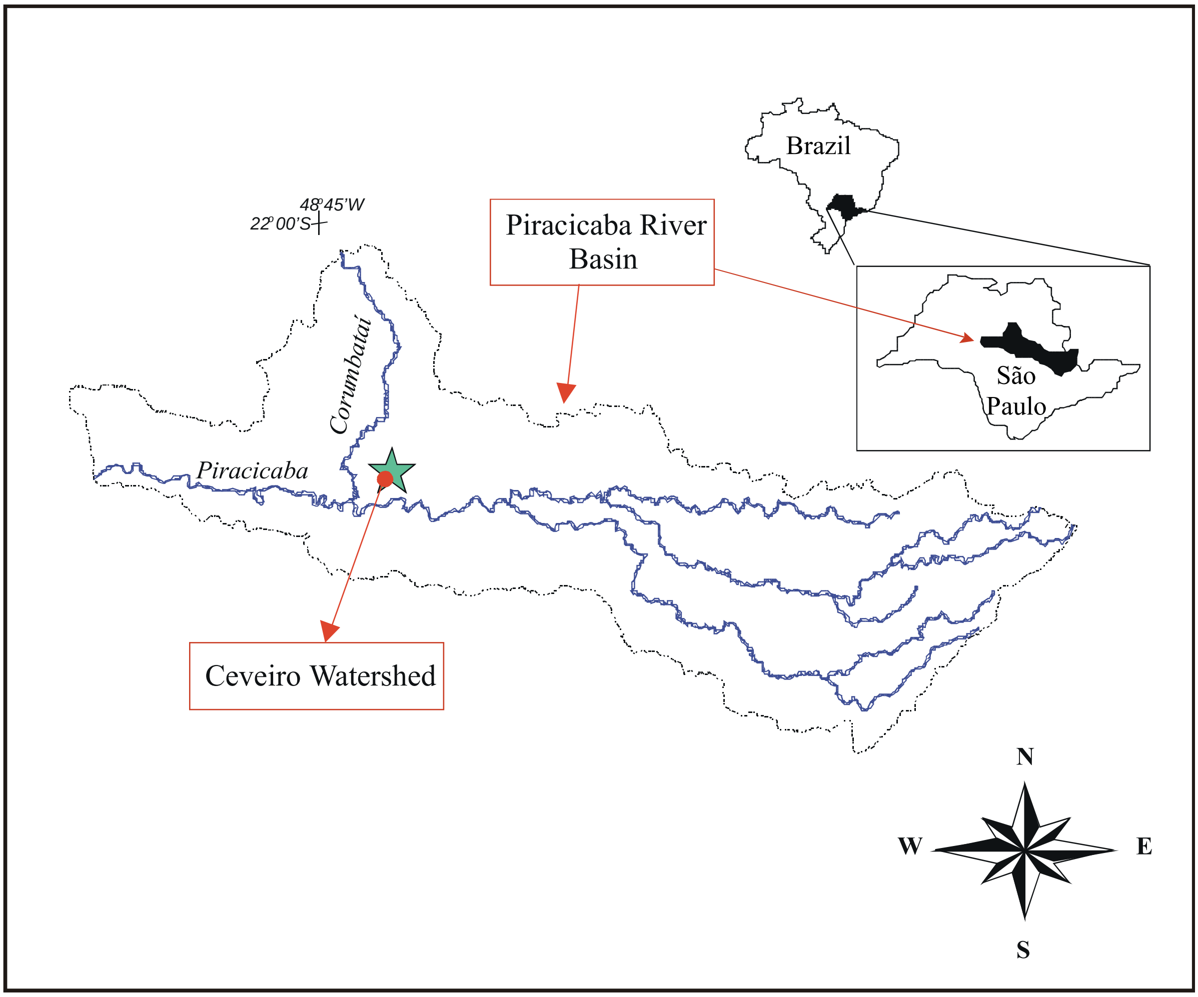

Fig. 2.8: Location of the Ceveiro study site (W74º 47’, S22º 40’).

The lithostratographic units of the catchment comprises three different geological formation ,dating from the Paleozoic to Cenozoic eras (Fig. 2.9). The floor of the basin and parts of the northfacing hills are formed by limestones, siltstones and shales of the late Permian Corumbatai formation, and the southfacing slopes by sandstones and claystones of the

Piramboia formation. Both formations are intrude by basaltic dykes of the Serra Geral Formation (Sparovek 2000).

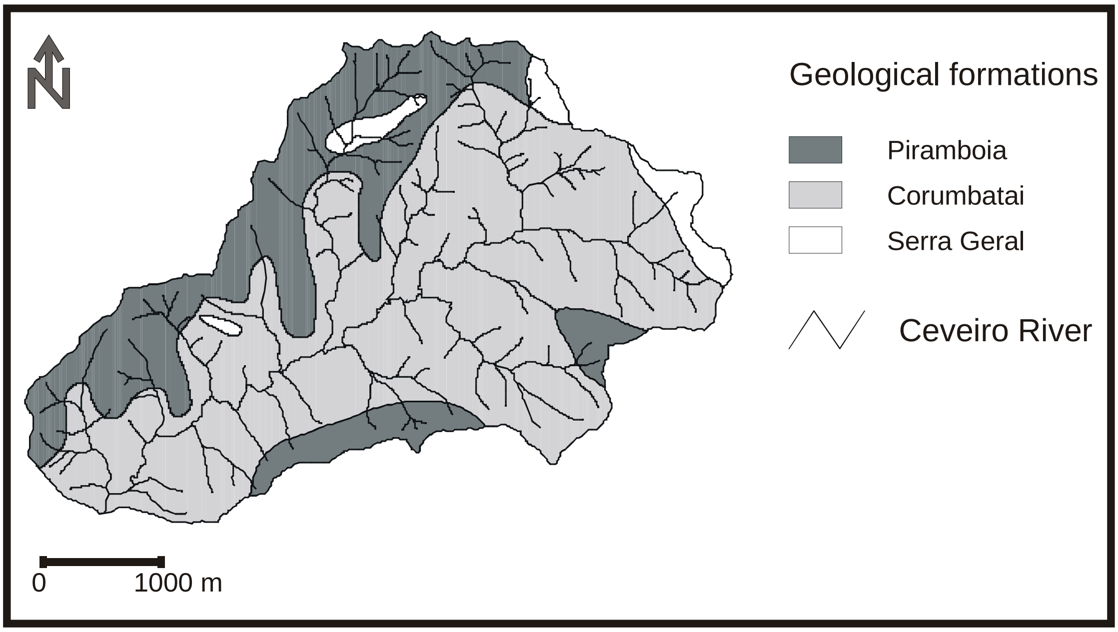

Fig. 2.9: Distribution of geological formations in the Ceveiro study site (W74º 47’, S22º 40’).

The landscape is characterised by presenting hills with altitudes ranging from 460 to 580 m and a rolling relief with an average slope ranging from 5 to 15 %. Areas with slopes lower than 2 % represent less than 5 % of the total area and are situated at crests and footslopes (Fig. 2.10).

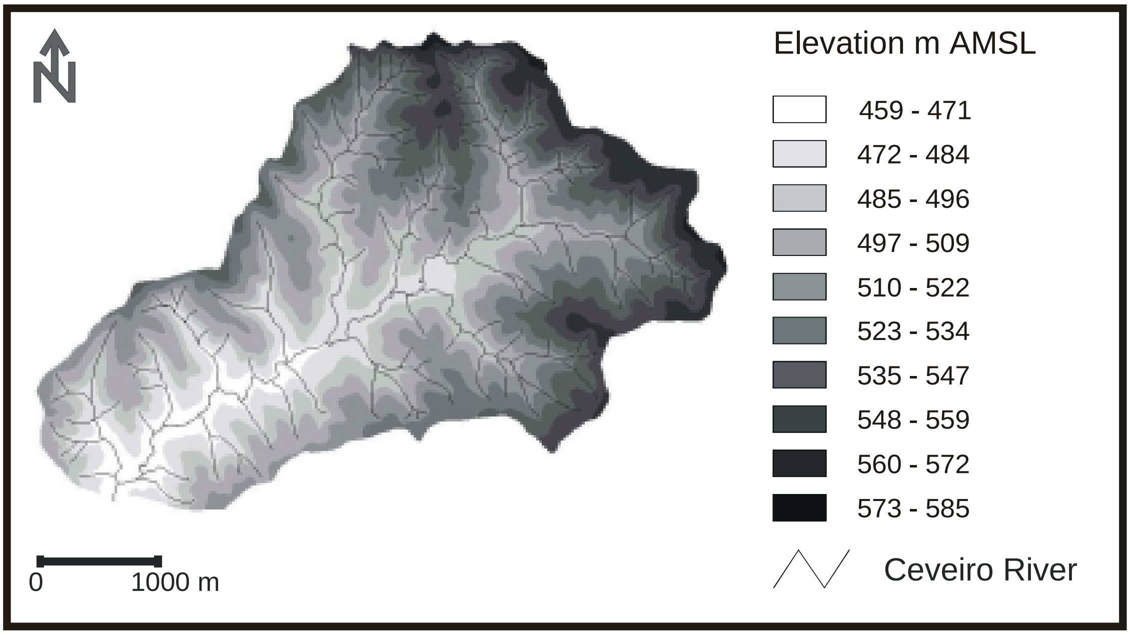

Fig. 2.10: Digital elevation model for the Ceveiro study site (W74º 47', S22º 40').

Parent material, climatic conditions and soil erosion gave rise to fourteen different soil types, which range from an average base saturation of 20 % to 64 % (Fig. 2.11). The two predominant soil types are an arenic Paleudult and a typic Udorthent which cover 45 % and 27 % of the catchment, respectively.

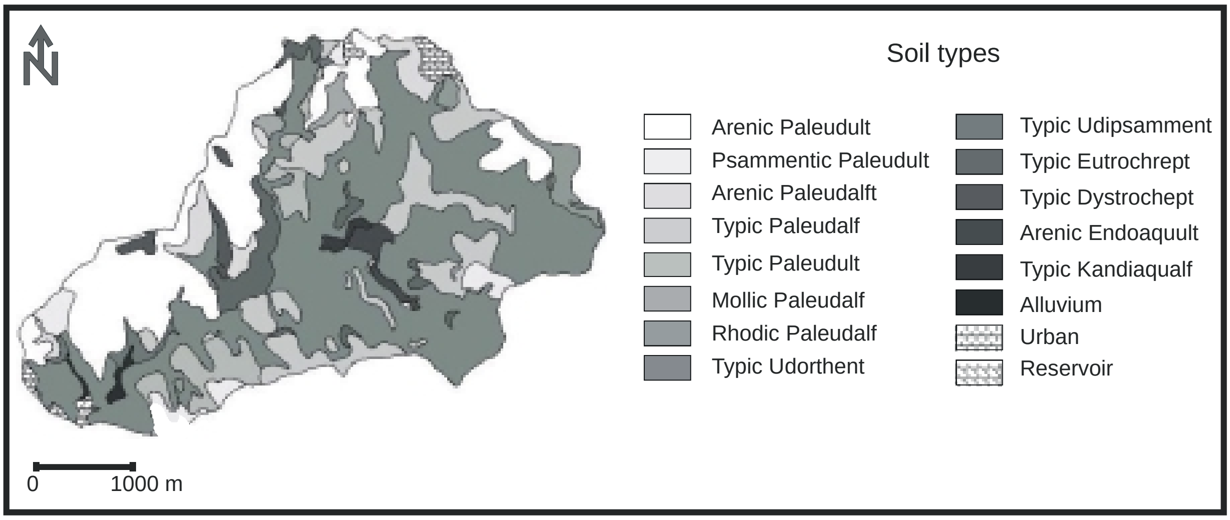

Fig. 2.11: Distribution of soil types within the Ceveiro study site (W74º 47', S22º 40').

Past soil erosion is evidenced by a mosaic of colours at the surface extending from grey colours at the top slope positions, characterising the original surface horizon, to strong yellow colours form the B_t horizon, originally at the depth of 1.0 m, at the mid slope (Pic. 3). At the end of the slopes and under pasture, a deep surface unstructured sandy horizon, indicating recent depositions, dominates. Ephemeral gullies are currently manifested at the end part of the slopes.

Pic. 3: Areal photograph of the Ceveiro study site (W74º 47’, S22º 40’).

Current land use comprises mainly sugar cane (70 %), riparian vegetation strips (regenerated forest), following the drainage lines (22 %) and to a small degree pastures (8 %) (Fig. 2.12). Sugar cane has been cultivated in the area for more than 20 years, whereby land preparation for cane field renewal, which includes fertiliser P application, coincides with the dry season. During the time of sampling plantations differed with respect to age of the cane and management practices. P is usually applied by subsurface banding at a depth of about 40 cm. The rotation cycle of the Sugar cane last on average four or five years. Traditionally, most sugar cane fields are burned prior to harvest (Maule et al., 1998). The distribution of land use between the two major soils types is illustrated in Figure 2.13.

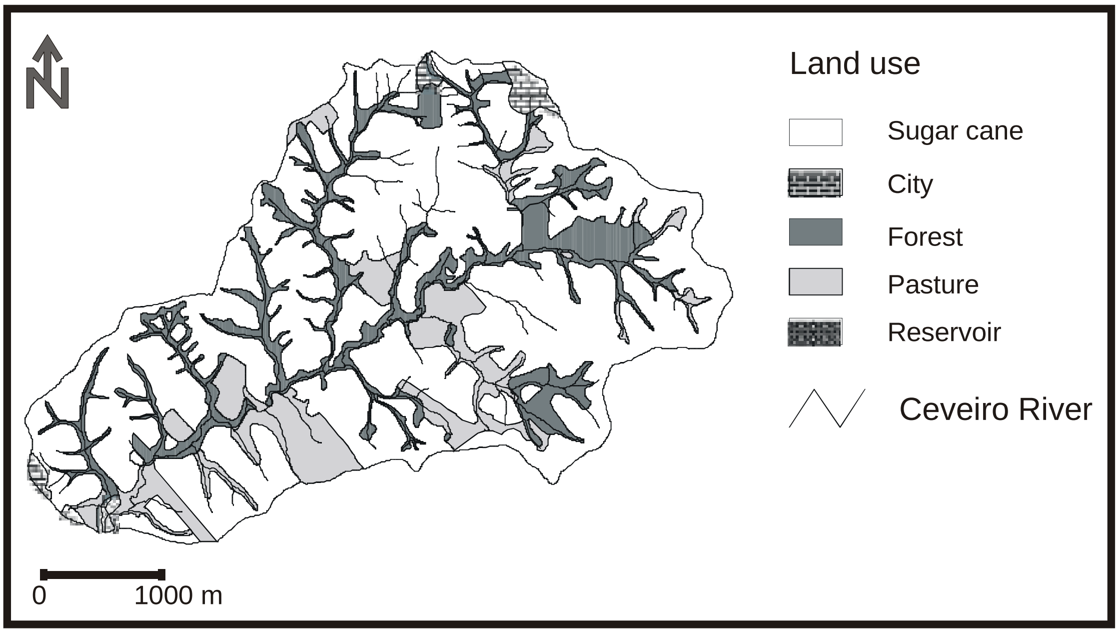

Fig. 2.12: Distribution of land use within the Ceveiro study site (W74º 47', S22º 40').

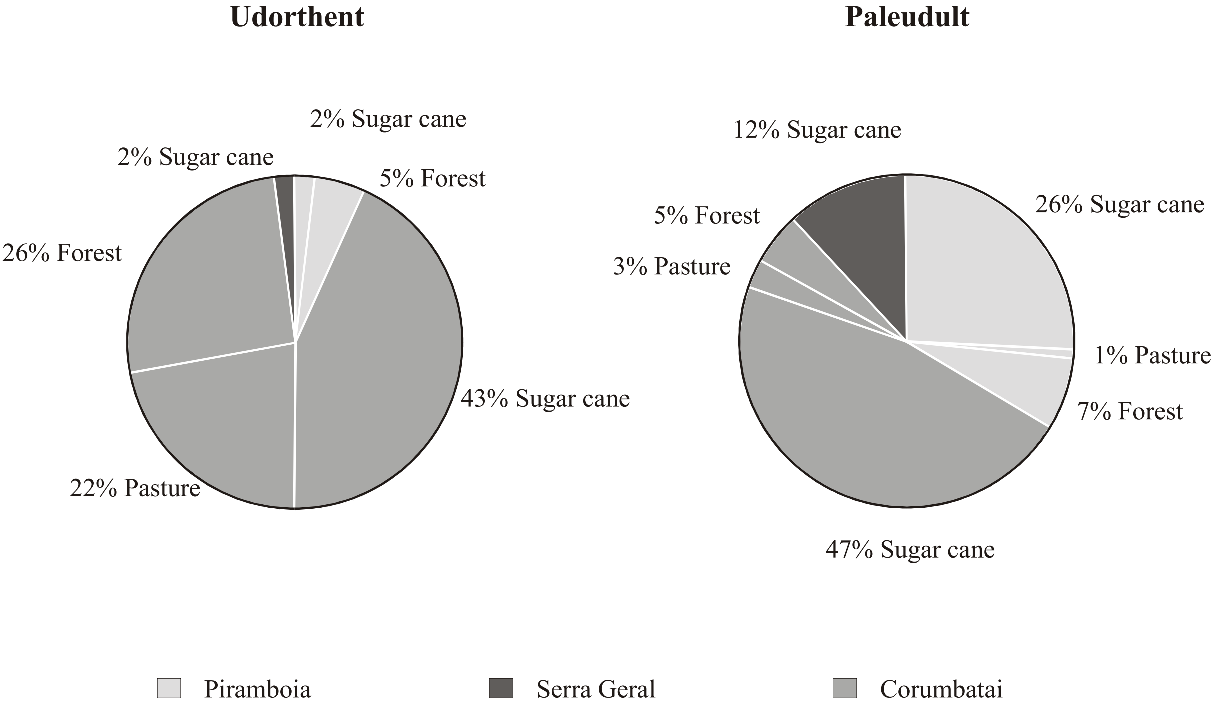

Fig. 2.13: Frequency distribution of the Udorthent and Paleudult at Ceveiro with respect to geology and land-use.

2.1.2 Chemical characteristics of the main soil types within the study sites

A summary of the chemical characteristics of the main soil types within the study areas is given in Table 2.3 (see as well Appendix, Tab. A.2-A.6).

Tab. 2.3: Average concentrations and relative standard deviation (RSD) in % for chemical soil properties of the main soil types within the study areas.

Soil parameters		Soil types							
		Arenic Paleudult (Ceveiro)		Typic Udorthent (Ceveiro)		Cambisol (Kassow)		Luvisol (Warberg)	
		mean	**RSD**	**mean**	**RSD**	**mean**	**RSD**	**mean**	**RSD**
$\text{PH}_{(CaCl_2)}$		4.28	10	4.65	11	5.74	14	6.99	5.7
$CaCO_3$	**%**	n.a.	-	n.a.	-	0.52	173	1.06	283
C_{tot}	**%**	13.2	68	24.1	53	0.88	23	1.12	45
Sand	**%**	78.3	14	36.0	57	63.9	7.4	3.01	71
Silt	**%**	10.1	52	31.9	33	27.1	11	72.3	17
Clay	**%**	11.6	59	32.1	41	9.61	19	24.7	46
Fe	**mg kg^{-1}**	1.02	118	2.23	46	1.10	36	1.54	19
Zn	**mg kg^{-1}**	16.3	130	37.96	66	4.20	21	53.80	36
P	**mg kg^{-1}**	9.68*	225	18.75*	115	55.5**	48	99.0**	35
CEC	**$mmol_c 100g^{-1}$**	52.0	44	126	46	6.52	52	26.2	21
	Ca^{2+} %	51		67		85		90	
	Mg^{2+} %	16		20		2		5	
	K^+ %	7		5		3		3	
	Na^+ %	n.a.		n.a.		1		2	
	Al^{3+} %	25		8		9		0	

Resin extractable P (van Raij et al., 1986),** CAL extractable P (Schüller, 1969), n.a. = not analysed

Kassow

The Cambisol at Kassow is characterised by a coarse texture, low organic matter content, and a moderate acidic pH, ranging from very acid (4.1) to neutral (7.2). About 16 % of the samples showed a $CaCO_3$ content of more than 1 %. As calcit does not occur naturally in these soils the high variability of the soil with respect to the $CaCO_3$ content is thought to be related to past lime applications. The estimated CEC was low, whereby the dominant cations in the soil solution were Ca^{2+} and K^{+}. The P adsorption capacity of soils in this area has been shown to be low, due to a low Kaolinit: Illit rate within the clay and silt fraction (Fiedler and Rotsche, 1976; Richter and Matzel, 1977). According to the LMS Schwerin (1994) fertiliser recommendation based on the CAL extraction method (Schüller, 1969), the P status of the Cambisol was below the optimum range.

The northern German till plains gave rise to extremely heterogeneous soils (Zarncke, 1989). This could be confirmed for the Kassow study site, as soil parameters investigated displayed very poor spatial autocorrelations (Tab. 2.4).

Tab. 2.4: Parameters for spherical semi-variogram models of main soil parameters of the Kassow study site (E12° 06', N53° 10').

	Direction	**Nugget (C_0)**	**(C_1)**	**Sill (C)**	**NR**	**Range a (m)**
pH	omni	0.5	0.37	0.87	58	112
	135°	trend				
$CaCO_3$	no spatial autocorrelation					
C_{tot}	omni	0.6	0.44	1.04	57	209
clay	no spatial autocorrelation					

Warberg

On average the Luvisol at Warberg can be described as silty loam. The average pH was found to be neutral, ranging from moderately acid (5.9) to slightly alkaline (7.8). The average $CaCO_3$ was twice as high as in the Cambisol, whereby the high variability was due to the presents of "Loesskindel". About 20 % of the soil samples showed a $CaCO_3$ content of more than 1 %. According to the LK Hannover (1998) fertiliser recommendation based on the CAL extraction method (Schüller, 1969), the P status of the field was well above the optimum range.

The Loess derived soils of the Boerde landscape are some of the most homogeneous soils in Germany (Altemüller, 1957). For all soil parameter analysed the Warberg study site displayed well behaved semi-variograms. Soil pH was found to have a strong spatial dependency, whereas the distribution of the $CaCO_3$ content was found to be nearly random (Tab. 2.5). Clay and Zn displayed moderate autocorrelation functions.

Tab. 2.5: Parameters for spherical semi-variogram models of main soil parameters of the Warberg study site (E10°54', N52°10').

	Direction	**Nugget (C_0)**	**(C_1)**	**Sill (C)**	**NR**	**Range a (m)**
pH	omni	0.20	0.67	0.87	23	95
Zn	omni	0.42	0.48	0.90	47	74
$CaCO_3$	omni	0.7	0.3	1.00	70	100
C_{tot}	omni	0.47	0.50	0.97	49	123
clay	omni	0.37	0.63	1.00	37	108

Ceveiro

Although both soils collected from the Ceveiro study site are highly weathered, acidic soils, they differ substantially with respect to their soil properties. The typic Udorthent is an Entisol, characterised by a poorly defined soil structure and a lower specific CEC (CEC per kg clay) when compared to the arenic Paleudult. The Udorthent, covering 27 % of the Ceveiro study site, was found to be a shallow, stony, poor clayey loam and was generally associated with steep slopes or underlain by rocks which are relatively resistant to weathering. On average the pH was found to be higher than in the Paleudult, ranging from extremely acid (3.6) to slightly acid (6.2). The dominant cations were Ca^{2+} and Mg^{2+} indicating the lower weathering state and association with the limestones, siltstones and shales of the Corumbatai formation (Fig. 2.13).

The Paleudult, a red yellow podzolic medium clay sand, belongs to the Utisols, characterised by an advanced weathering stage. Vertical clay illuviation caused a depletion of the topsoil with respect to clay and iron particles. The pH was found to range from extremely acid (3.6) to neutral (6.9). The dominant cations within the soil were Ca^{2+} and Al^{3+}. The organic matter content was on average 10 % lower than in the Udorthent.

Based on the general P-fertiliser recommendation for sugarcane production the two tropical soils were found to be deficient with respect to plant available P, whereby 2 % of the arenic

Paleudult was above the deficiency threshold of 76.5 µg cm^{-3} resin extractable P and 11 % of the typic Udorthent, respectively (Boletim 100, 1996).

Due to the patchy distribution of the soil types (Fig. 2.11) and the low sampling density (Appendix, Fig. A.3) it was not possible to investigate the spatial distribution of soil parameters for each soil type separately. Given the total area of the study site and the variety of soil types and land-uses the main soil properties were found to display relatively strong spatial patterns (Tab.2.6).

Tab. 2.6: Parameters for spherical semi-variogram models of main soil parameters for the Ceveiro study site (W74° 47’, S22° 40’).

	Direction	**Nugget (C_0)**	**(C_1)**	**Sill (C)**	**NR**	**Range a (m)**
pH	omni	0.55	0.40	0.95	58	200
Ca^{2+}	53°	0.45	0.40	0.85	47	191
	143°			trend		
C_{tot}	53°			trend		
clay	omni	0.09	0.44	0.53	17	289

2.2 Sampling procedures

2.2.1 Kassow and Warberg

In Kassow and Warberg geocoded topsoil (0-20 cm) samples were taken in a grid, whereby 6 sample cores were collected per sampling point within a radius of < 1 m. Sample cores were mixed, air-dried and passed through a 2 mm sieve prior to analysis. In Kassow sampling was carried out in July 1996. A total of 190 samples were taken in a 50 m grid (Appendix, Fig. A.1). In Warberg sampling was conducted at two occasion, once in August 2000 after winter wheat harvest and in November 2000 after sugar beet harvest. In total 405 soil samples were taken in a 30 m grid (Appendix, Fig. A.2).

2.2.2 Ceveiro

In Ceveiro a total of 300 geocoded soil samples were collected. The samples were taken over a period of two years (Sparovek et al., 2001). Samples were taken either by using an auger sampler or directly from the pit. The entire soil profile was sampled in 20 cm steps. Samples were air-dried and passed through a 2 mm sieve prior to analysis. In the present research work only the surface samples (0-20 cm) were utilised. For the purpose of geostatistical analysis two sampling strategies were carried out. 58 soil samples were taken in a 25 m grid from a sugar cane field (Appendix, Fig. A.3). Stratified random sampling, comprising the grid and additional 35 samples were collected in order to include samples from all land-use and parent material. The average distance of the samples was 110 m. Additionally, 200 samples were taken randomly over the entire area of the catchment. The average distance of the samples was about 400 m.

2.3 Analytical methods

2.3.1 Soil analysis of main chemical properties

All analytical methods were carried out on air-dried soil samples < 2 mm. For main chemical properties soil analysis commenced at two different laboratories. The temperate soil samples from Kassow and Warberg were analysed at the Institute of Plant Nutrition and Soil Science of the Federal Agricultural Research Centre (FAL-PB), in Braunschweig, Germany, whereas the tropical soil samples from Ceveiro were analysed at the laboratory of Luiz de Queiroz - College of Agriculture (ESALQ) in Piracicaba, Brazil (Tab. 2.7 & Tab. 2.8).

Tab. 2.7: Soil analytical methods employed at the Institute of Plant Nutrition and Soil Science of the Federal Agricultural Research Centre (FAL-PB) in Braunschweig, Germany for soil samples collected at Kassow and Warberg.

Parameter	**Method**
plant available P*	Calcium-Acetat-Lactat (CAL)-Extraction (Schüller, 1969): Colourimetrical analysis using a Perkin-Elmer 550SE UV/VIS Spectrophotometer
total Fe	Aqua regia extraction (AbfKlaerV, 1992) followed by Atomic Absorption Spectroscopy (AAS; UNICAM 929)
total Zn	Aqua regia extraction (AbfKlaerV, 1992) followed by AAS (UNICAM 929)
plant-available Zn	0.43 HNO_3 extraction (WESTERHOFF, 1954/1955) followed by AAS (UNICAM 929)
exchangeable cations	NH_4acetate extraction, (Meiwes et al., 1984); Na, K by emission spectroscopy using flame photometer (ELEX 6361); Ca, Mg by AAS (UNICAM 929)
C_{tot}	Dry combustion (LECO EC-12®, Model 752-100)
ph	Potentiometrically in 0.01M $CaCl_2$ suspension using a Methrohm 605 pH meter (VDLUFA-Method, Hoffmann, 1991)
$CaCO_3$	Volumetrically by means of "Calcimeter" (König, 1923)
clay	Indirect determination using soil Rb concentration (Schnug and Haneklaus, 1996)
particle size	Sedimentation by hydrometer analysis (De Leenheer et al., 1954)

*The CAL-Method was carried out on all samples from Kassow and 10 randomly selected samples from each field in Warberg.

Tab. 2.8: Soil analytical methods employed at the ESALQ (Luiz de Queiroz - College of Agriculture), for soil samples collected at Ceveiro, Piracicaba, Brazil.

Parameter	**Method**
exchangeable cations	Ion exchange resin (Raij et al., 1986)
C_{org}	Walkley-Black (Walkley, 1935)
plant-available P	Anion exchange resin (Raij et al., 1986)
particle size	Particle < 2 mm pipette method using a filter candle system (Camargo et al., 1986)

2.3.2 Soil analysis to determine different P fractions

For the extraction of individual soil P fractions, representative of functional soil P pools all soil samples from Kassow, Warberg and Ceveiro were analysed at the laboratory of FAL-PB

(Tab. 2.9). With the exception of P in the aqua regia extraction, which was analysed using an ICP QMS (Plasma Quad 3, VG Elemental), P was determined colourimetrically (Perkin-Elmer 550SE UV/VIS Spectrophotometer), according to John (1968) and Schüller (1969).

Tab. 2.9: P extraction methods employed to analyse soil P fractions for soil samples collected at Kassow, Warberg and Ceveiro (analysis were conducted at FAL-PB).

Name	**Extractant**	**Soil/solution ratio**	**Reference**
$CaCl_2$	0.01 $CaCl_2$	1:10	Schachtschable (1954)
AAC	0.5M CH_3COONH_4 + 0.5M CH_3COOH + 0.02M Na_2EDTA, buffered at pH 4.65	1:10	Sillanpää (1982)
WH	0.43M HNO_3	1:10	Westerhoff (1954/55)
Aqua Regia (AR)	conc. HNO_3 + conc. HCl	1:20	AbfKlaerV (1992)

2.4 *Quality assessment of P extraction methods used*

2.4.1 *Accuracy*

As the concentration of plant available fractions within a soil samples varies continuously only the total concentration of P in a soil can be measured accurately (Houba et al., 1994). To asses the accuracy (Mariott, 1990) of the AR method reference material from the Wageningen International Soil-Analytical Exchange Programme (WEPAL, 2000) was analysed for total P. The material used were a sandy soil from Tanzania, a river clay and a clay from the Netherlands and a sandy soil from Mali. The results of the extractions were compared to the median (excluding all outliers, Houba et al., 1996) of the published results obtained by other laboratories using a) true total analysis to assess the relative extraction force of the AR method and b) so-called “total” analysis to assess the accuracy of the AR-method (WEPAL, 2000). When compared to the results of 68 laboratories for acid extractable soil P the P in AR deviated less than 10 % from the median, showing an acceptable accuracy of the method. In comparison to the median of the results for real total P analysis the AR method extracted on average 82 % of the total P in the soil (Tab. 2.10).

Tab. 2.10: Median total P concentration (mg kg^{-1}) of reference material from the Wageningen International Soil-Analytical Exchange Programme (WEPAL, 2000) analysed using the AR-method, true total analysis and so-called total analysis (the median was calculated excluding all outliers (Houba et al., 1996)).

Methods		**Reference material (WEPAL, 2000)**			
		Sandy soil Tanzania	**River clay Netherlands**	**Clay Netherlands**	**Sandy soil Mali**
AR	median	721	1187	1705	75
	n	5	5	5	5
true total analysis **(HF-treatment, alkaline fusion, X-ray fluorescence, neutron activation analysis)**	median	861	1407	1952	103
	n	21	21	21	19
so-called total analysis **(different methods e.g. boiling acid mixtures)**	median	771	1272	1805	71
	n	68	68	67	63

2.4.2 Extraction force

Fitts (1956) demonstrated in a comprehensive study how various soil properties influence the results of P extraction methods. The extraction force of the extractants used in the present work ($CaCl_2$, AAC, WH, AR), was therefore, established by extracting reference material for each study site. The reference material was produced by selecting randomly 10 samples for each parent material. Homogenising was done by grinding the soil to pass a mesh smaller than 0.5 mm and mixing thoroughly. P was extracted in fivefold replication from all reference material using $CaCl_2$, AAC, WH, AR, H_2O, Bray and Olsen (Tab. 2.11).

Tab. 2.11: Extraction methods used for extracting the P concentration of parent material within Kassow, Warberg and Ceveiro.

Name	Extractant	Soil/solution ratio	Reference
H_2O	H_2O	1.5:60	Van der Paauw et al. (1971)
$CaCl_2$	0,01 $CaCl_2$	1:10	Schachtschabel (1954)
Olsen	0.5M$NaHCO_3$	1:10	Olsen et al. (1954)
CAL	0.1M Ca-lactate + 0.1M Ca-acetate + 0.3M CH_3COOH	1:20	Schüller (1969)
AAC	0.5M CH_3COONH_4 + 0.5M CH_3COOH + 0.02M Na_2EDTA, buffered at pH 4.65	1:10	Sillanpää (1982)
WH	0.43M HNO_3	1:10	Westerhoff (1954/55)
Bray I	0.025N HCl +0.03N NH_4F	1:10	Bray and Kurtz (1945)
AR	conc. HNO_3 + conc. HCl	1:20	AbfKlaerV (1994)

When no complexing actions by the extractant are involved, the amount of P extracted is a function of the pH, whereby the pH determines not only the dissolution of the soil P, but also the reprecipitation of the dissolved P. In general the results of the comparative study followed this trend, whereby the lowest P concentration was found in the near neutral extracts $CaCl_2$ and H_2O, whereas the solubility of soil P increased to the acid and alkaline sides (Tab. 2.12, Appendix, Tab. A.1).

Tab. 2.12: Average P concentrations (mg kg^{-1}) and RSD values (%) of reference material analysed in fivefold replication using $CaCl_2$, AAC, WH, AR, H_2O, Bray I and Olsen.

Soil P pool		**Extractant**	**Reference material**									
Guo and Yost (1998)*	**Common names**		**Piramboia (Ceveiro)**		**Corumbatai (Ceveiro)**		**Serra Geral (Ceveiro)**		**Cambisol (Kassow)**		**Luvisol (Warberg)**	
			Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD
readily plant available P	**soluble P**	**$CaCl_2$**	0.13	14.6	0.031	22.8	0.026	0.0	4.15	1.7	0.73	1.6
		H_2O	5.50	4.1	4.75	4.2	8.56	1.2	15.8	2.3	11.0	1.0
reversibly plant available P	**plant available P**	**OLSEN**	13.7	5.5	7.5	6.7	14.0	2.4	30.8	2.7	29.0	2.3
		AAC	17.0	1.0	2.96	1.6	6.16	5.0	85.3	7.0	121.2	0.5
		CAL	17.1	3.1	3.92	6.9	6.38	1.8	65.7	3.4	85.5	2.1
		WH	25.8	1.4	4.91	3.6	11.0	1.2	182.1	2.0	150.7	3.0
		BRAY I	34.5	1.6	9.45	2.1	17.9	2.0	146.9	1.2	88.5	3.0
sparingly available P	**total P**	**AR**	143.9	0.6	136.9	1.7	424.3	0.9	478.4	1.1	472.6	3.3

* terminology adopted in this work

The difference in extraction force was statistically analysed by ANOVA and a subsequent Duncan-Test (Tab. 2.13). The test showed that $CaCl_2$, AAC and AR differed significantly in their extraction force, independent of the reference material used. Lowest P concentration was analysed in $CaCl_2$, followed by AAC and AR. The P concentration in WH was found to be significant higher than in $CaCl_2$ and significant lower than in AR. However, no significant difference was found for WH and AAC.

Tab. 2.13: Results of the Duncan test, comparing the extraction force of different P extraction methods. Means of homogeneous subsets of extraction methods that do not differ significantly with respect to their extraction force are displayed.

		Subsets for alpha = 0.5				
Extraction method	**n**	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**
$CaCl_2$	25	1.01				
H_2O	25	9.13	9.13			
Olsen	25	19.0	19.0	19.0		
CAL	25	35.7	35.7	35.7	35.7	
AAC	25		46.5	46.5	46.5	
Bray	25			59.5	59.5	
WH	25				74.9	
AR	25					289
sig.		0.10	0.08	0.05	0.06	1.00

When comparing the means of the two methods separately for the temperate material and the tropical material it could be shown that for the former no significant differences were found, whereas for the latter WH extracted significantly more P than AAC.

2.4.3 Precision

For the purpose of this study, which aimed at investigating the within field variation of soil P concentration it was important that the precision (Mariott, 1990) of the methods used was well below the average within field RSD. In order to access the precision of the P extraction methods used reference material was produced by homogenising randomly selected samples from each study site and analysed in fivefold replication (see Chapter 2.4.2).

For the reference material of each study site the RSD values of the four extraction methods, $CaCl_2$, AAC, WH, AR were well below 5 % (Chapter 2.4.2, Tab. 2.12). For Warberg, the study site with the most homogeneous soil, the within field variation ranged from an RSD of 23 % to 83 % (Chapter 3.1, Tab. 3.1–3.5). The precision of the methods used, was therefore, evaluated as being sufficient. In addition, when compared to standard soil P test methods the RSD values did not differ (Tab. 2.12).

2.5 Landscape analysis

2.5.1 Digital elevation model (DEM)

For Kassow, the DEM was kindly provided by the KSG Agrargesellschaft mbH in Kassow. The DEM was based on a 1:5000 scale topographic map updated with airborne laser scanning, as well as in field GPS readings (Thiessenhuse, 1998). In Warberg, the DEM used was calculated by photogrammetry based on airborne photographs and 1:5000 scale topographic maps (LGN, 1998). For Ceveiro, the DEM was generated by triangulated irregular network (TIN) based on digitised contour lines from a 1: 10000 topographic map (Sparovek et al., 2001).

2.5.2 Derivation of terrain attributes

Terrain attributes were calculated based on a 12.5 m horizontal resolution digital elevation models. The principal attributes slope, profile curvature and plan curvature were calculated using the ArcView extension DEMAT (Behrens, 1999). For Kassow and Warberg slope was calculated according to Horn (1981), whereas for the Ceveiro study site the method of Zevenbergen and Thorne (1987) was used.

The profile curvature describes the shape of the slope in the direction of steepest ascent or decent and indicates the rate of change of the potential gradient, which is important for water flow and velocity and sediment transport processes. In contrast the plan curvature is a indicator of topographic convergence and divergence and hence correlates to the volume of water across a landscape.

Secondary terrain attributes, such as the wetness index and the LS factor were calculated using the map calculator provided by Arc View, 3.2a. The wetness index was used to identify areas of surface saturation and soil water content (Moore et al., 1993) and was calculated as follows:

$$\omega = \ln \frac{A_s}{\tan \beta}$$

where A_s is the specific catchment area and β is the slope gradient. Specific catchment area is the drainage per unit width (in this case 12.5 m) orthogonal to a stream line. Additionally, the slope length factor (LS factor) was calculated according to Moore and Burch (1986):

$$LS = \left(\frac{A_s}{22.13} \right)^{0.4} * \left(\frac{\sin \beta}{0.0896} \right)^{1.3}$$

The LS factor indicates the erosion potential of a slope, which is a function of slope length and slope steepness. L is the slope length factor and is calculated as the ratio of soil loss from the field slope length to that from a 22.13-meter length on the same soil type and gradient. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition. S is the slope steepness, and is calculated as the ratio of soil loss from the field gradient to that from a 9 percent slope under otherwise identical conditions.

2.6 Statistical analysis

2.6.1 Principal component analysis and general linear model

Statistical analysis was conducted employing the SPSS statistical package Version 10. Principal component analysis and variography are not standard statistical procedures employed in plant nutrition research. Thus, the following two chapter will explain the basics for a better understanding of the presented results. For a deeper treatise of classical statistics the reader may refer to Schnug (1985), Webster and Oliver (1990), Cressie (1993), Venables and Ripley (1999).

The most frequently statistics used to describe the relation between two variables, are the covariance and its standardised form, the linear correlation coefficient. The covariance σ_{ij} is a measure of the joint variation of Z_i and Z_j around their means. It is computed as:

$$\sigma_{ij} = \frac{1}{n} \sum_{\alpha=1}^{n} \left(z_i(\alpha) - \mu_i\right) * \left(z_j(\alpha) - \mu_j\right)$$

where μ_i and μ_j are the arithmetic means of variables Z_i and Z_j, respectively. The correlation coefficient ρ_{ij} is readily deduced as:

$$\rho_{ij} = \frac{\sigma_{ij}}{\sigma_i * \sigma_j} \qquad \in [-1,1]$$

where σ_i and σ_j are the standard deviations of variables Z_i and Z_j, respectively. The unit-free correlation coefficient is easier to interpret than the covariance, which depends on the measurement scales of the two variables. However, it is important to note that ρ_{ij} is only a measure of *linear relation* between two variables. Like the variance, the correlation coefficient ρ_{ij} is strongly affected by extreme values. A more robust measure is the rank correlation coefficient $\rho_{Rij,}$ which considers the ranks of the data, $r(z_i(\alpha))$ and $r(z_j(\alpha))$, rather than the original values:

$$\rho R_{ij} = \frac{1}{n} \frac{\sum_{\alpha=1}^{n} \left[r(z_i(\alpha)) - \mu R_i\right] * \left[r(z_j(\alpha)) - \mu R_j\right]}{\sigma R_i * \alpha R_j}$$

where μR_i and σR_i are the mean and standard deviation of the n ranks $r(z_i(\alpha))$. A large deviation between ρ_{ij} and ρ_{Rij} reflects either a non-linear relation between the two variables Z_i and Z_j or the presence of pairs of extreme values.

Principal component analysis

Principal components analysis (PCA) is used to form a subset of uncorrelated theoretical variables called principal components (PC) that adequately explain the variation in the original variable set. The main applications of factor analytic techniques are: (1) to reduce the number of variables and (2) to detect structures in the relationship between variables, that is to classify variables. Therefore, factor analysis is applied as a data reduction or structure detection method. Groups of correlated variables were defined for each study site using the principal component procedure provided by the SPSS software.

This method uses linear transformation of original variables to create a new set of uncorrelated variables, called the principal components (PC) that can be used in a regression model. The method is a three step procedure, whereby (i) input data are standardised (ii) the correlation matrix are compute (iii) extraction of eigenvalues and eigenvectors from the variance-covariance matrix. PC are obtained by projecting the multivariate datavectors on the space spanned by the eigenvectors. Whereby the eigenvector associated with the largest eigenvalue has the same direction as the first PC and shows the largest variance of the projected data. The eigenvector associated with the second largest eigenvalue determines the direction of the second PC, displays the next largest variance and is orthogonal to the first, and so on. The sum of the eigenvalues equals the trace of the square matrix and the maximum number of eigenvectors equals the number of rows (or columns) of this matrix. The PCs exhibit no multicollinearity in a regression, and thus important coefficients can be easily determined. If the coefficients of the PCs' transformations imply meaningful interpretation of the components, the PC regression may shed light on the underlying regression relationship. The component matrix was calculated for Varimax rotation with Kaiser Normalisation for all eigenvectors with an eigenvalue larger than 1.

General linear model (GLM)

In the present research work the GLM was carried out to asses the influence of topography, landuse, geology and soil texture classes on the joint distribution of P species.

The GLM Multivariate procedure provides regression analysis and analysis of variance (ANOVA) for multiple dependent variables by one or more factor variables or covariates. The factor variables divide the population into groups. Using this GLM procedure, one can test the null hypothesis about the effects of factor variables on the means of various groupings of joint distribution of dependent variables. The GLM can be written as:

$$y = X\beta + \varepsilon$$

where y represents the vector of observed data, β is an unknown vector of fixed-effect parameters with known design matrix X, and ε is an unknown random error vector modelling the statistical noise around the linear equation. The focus of the standard linear model is to model the mean of y by using the fixed-effect parameters β. The residual errors ε are assumed to be independent and identically distributed Gaussian random variables with mean = 0 and variance σ^2. Given samples collected on systematic grids or transects, the residual errors ε can not longer be assumed to be spatial independent (Cook and Pocock, 1983; Lark, 1999). To circumvent the problem Cook and Pocock (1986) proposed an approach to fit a regression model by Maximum Likelihood. This was done employing the Mixed Procedure provided by SAS software (Litell et al., 1996). The mixed linear model is a generalisation of the standard linear model used in the GLM procedure, the generalisation being that data are permitted to exhibit correlation and nonconstant variability:

$$y = X\beta + Z\gamma + \varepsilon,$$

here γ is an unknown vector of random-effects parameters with known design matrix Z, and ε is an unknown random error whose elements are no longer required to be independent and homogeneous. The model was estimated using restricted maximum likelihood. Using this approach, the variance-covariance components are estimated via maximum likelihood, averaging over all possible values of the fixed effects. The fixed effects are estimated via general least square given these variance-covariance estimates.

For all three study sites the covariates tested were slope, elevation, profile curvation, plan curvation and LS factor. For the Kassow data set fertilisation was included as an additional variable. Fertilisation rates were extracted for each sampling point from the DARM (Chapter 2.1.1, Fig. 2.4) using the Arc View, Version 3.2 extension Grid Analyst. For Kassow, and Warberg soil texture classes were tested as fixed factors. Additionally, Warberg was tested for the effects of fields and their interaction with soil texture classes. The Ceveiro data set was analysed using geology, soil and land-use as fixed factors, whereas their interactions were tested as random effects. Prior to analysis data was normalised using normal score transformation (Chapter 2.6.3).

2.6.2 Variography

The variability in field-based attributes such as soil properties or crop yield have been routinely analysed using classical statistical approaches which assume that the expected value for any of these attributes (*z*) at any location within a field (or sampling area)(*x*) is calculated as:

$$E[z(x)] = \mu + \varepsilon(x)$$

where μ is the population mean and ε(x) a random, spatially uncorrelated spread of values about the mean which is assumed to be normally distributed with zero mean and variance = σ^2.

In reality, quantifying the probability distribution of a population (Z) is achieved using the central tendency and distribution of a sample population (Z').The central tendency of a sample *{z(α), α=1,...,n}* may be described by the mean (μ):

$$\mu = \frac{1}{n}\sum_{\alpha=1}^{n} z(\alpha)$$

and the distribution is commonly characterised by the variance (σ^2) or its square root, the standard deviation (σ) of the sample population, where:

$$\sigma^2 = \frac{1}{n}\sum_{\alpha=1}^{n}\left(z(\alpha)-\mu\right)^2$$

In many studies, the variance and standard deviation are often found to be proportional to the mean. It is, therefore, common practice to compare variability between sample populations using the more stable relative standard deviation (RSD):

$$RSD = \frac{\sigma}{\mu} * 100$$

These classical procedures are based on the assumption that the variation observed in the samples is not spatial correlated, but, randomly distributed. Classical statistics, therefore, provides only a universal description of the population variability for the entire sampling area.

The fundamental difference between classical statistics and geostatistics (variography) is that the later is based on the theory of regionalised variables (Matheron, 1971; Journal and Huijbredgts, 1997) which states that observations are not independent of each other, but instead that on the average, observations closer together are more similar than those further apart. For a general introduction into geostatistical methods one may refer to Burgess and Webster (1980), Isaaks and Srivastava (1989) and Journel (1989). For recent revues on the use of geostatistics in soil science one may consult Goovaerts (1999), Goovaerts (2001), Heuvelink and Webster (2001) and Lark and Webster (2000).

Geostatistical techniques include variography (Isaaks and Srivastava, 1989), which is one way of modelling the spatial continuity of soil parameters and kriging (Krige, 1951), which provides estimates of soil parameters at unsampled locations. For the present work variography was the main technique employed to investigate the spatial speciation of soil P. The following paragraph gives a brief description of its principles.

The semi-variogram is a measure of the average degree of dissimilarity between two data points (Fig. 2.14d). Because the underlying processes that govern the spatial distribution of data often have preferred orientations, data may change more quickly in one direction than another. Distributions that have preferred orientations are called anisotropic, whereas otherwise it is referred to be isotropic. The distance between two observations is therefore described by a vector h, the so called lag. Thus the semi-variogram is a three dimensional function, consisting of two independent variables the direction and the distance and one dependent variable the observation z(x_i). It is computed as half the average squared difference between the components of each data pair:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}[z(x_i)-z(x_i+h)]^2$$

where N(*h*) is the number of data pairs separated by the lag *h*, [z(x_i)-z(x_i+h)] is the h-increment of attribute z.

Fig. 2.14 illustrates various graphical presentations of spatial continuity. The *sample map* can be used to identify errors in the coordinates and data clustering(Fig. 2.14a). Pairs of data can also be visualised on this map.

An *h-scatterplot* is the bivariate equivalent of the histogram (Fig. 2.14b). The value of one variable at position x is plotted against the value of the same variable at position x + h. In this way it provides an effective way to grasp the notion of spatial continuity. It is also effective to detect outliers in the data set.

The *variogram surface* offers a global view of the variogram values in all direction (Fig. 2.14c). As such it is subsidiary for detecting anisotropies in the pattern of spatial continuity (Deutsch and Journal, 1998).

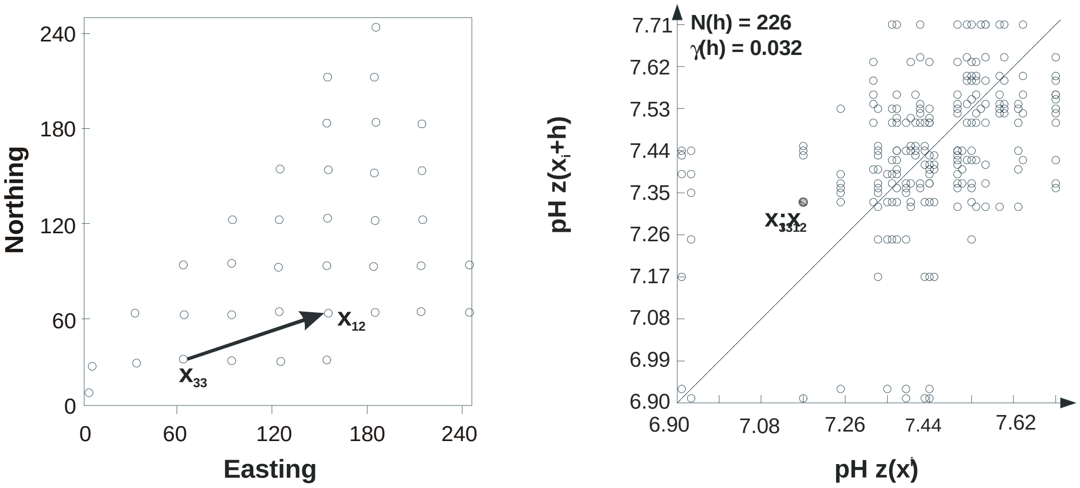

Fig. 2.14a: Map of sampling points.

Fig. 2.14b: H-scattergram

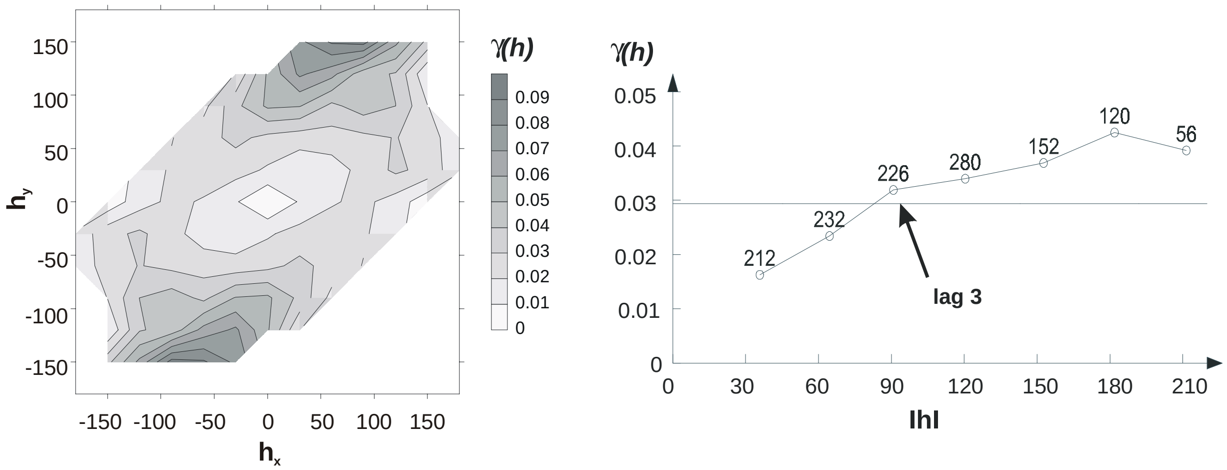

Fig. 2.14c: Variogramsurface

Fig. 2.14d: Experimental semi-variogram

Fig. 2.14: Various views of spatial continuity and their relationships (adapted from Pannatier, 1996).

To gain information about the spatial distribution of data it is necessary to fit a model through the experimental semi-variogram. In the present work semi-variogram models with nugget and spherical fit of the curve were used:

$$\gamma(h) = \begin{cases} nugget + sill * \left[\frac{3}{2}\frac{h}{range} - \frac{1}{2}\left(\frac{h}{range}\right)^3\right] & for \quad 0 \le h \le range \\ nugget + sill & for \quad h = range \\ 0 & for \quad h = 0 \end{cases}$$

The model begins from an intercept at $|h| = 0$ which is called the nugget variance C_0. At the intercept the model has a nearly linear behaviour and rises to a plateau in the distance, the so called sill. The sill gives an estimation of the total variance of the data. The distance at which the model reaches the sill is called the "range". All data within this range are assumed to be spatially autocorrelated (Fig. 2.15).

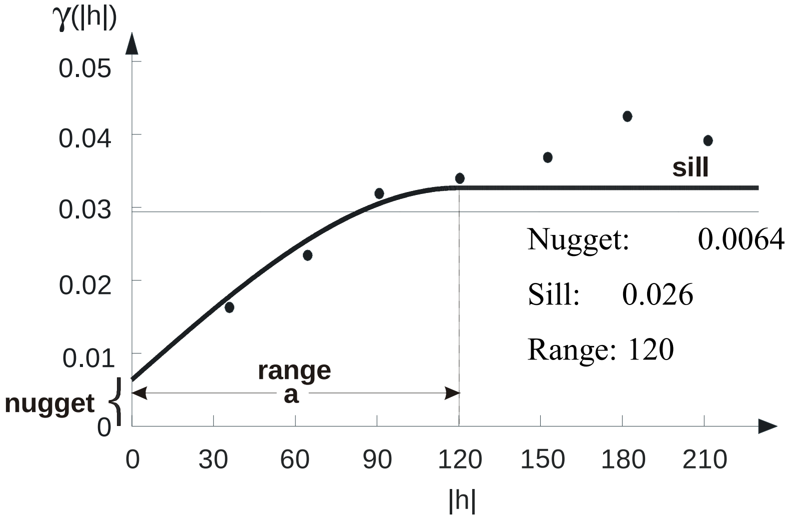

Fig. 2.15: Spherical model with nugget effect fitted to the experimental semi-variogram for soil pH in Warberg (field BB).

The nugget effect represents the variation of the data set, that arises firstly, from measurement error and secondly, from a spatial variability at distances smaller than the shortest sampling interval. The structural semi-variance C_1 represents the component of total variation contributed by systematic sources. A quantification of the contribution of random variation to the semi-variance observed in a data set can be estimated from the ratio of nugget semi-variance to sill semi-variance (Trangmar et al., 1985):

$$NR = \frac{C_0}{C_0 + C_1} * 100$$

This ratio has been used to describe the strength of the spatial dependence within a field attribute (Cambardella et al., 1994) where:

$NR \leq 25\,\%$: indicates a strong spatial dependency

$25\,\% < NR < 75\,\%$: indicates a moderate spatial dependency

$NR \geq 75\,\%$: indicates weak spatial dependency

Considering that the modelling of an experimental semi-variogram is highly subjective (Schaeben, 2001) the emphasis in this study was placed on finding the model which represented best the specific features of the study sites, rather than having the best statistical fit (Goovaerts, 1997). Ancillary information which were tested (Chapter 2.6.1) to have an effect of the distribution of soil parameters such as topography, distribution of different soil texture classes, tilling practices and fertiliser placement were used to decide on anisotropy directions, ratio, and range. For variogram analysis the geostatistical software package Variowin Version 2.2 (Pannatier, 1996) was employed.

2.6.3 Data transformation

Normal score transformation

If the distribution of variables was not multiGaussian, the variables were transformed using normal score transformation. This is a three step approach whereby, continuous numeric data are converted to a discrete number of categories. Firstly, the n original data z(x) are ranked in ascending order, secondly the sample cumulative frequency of the datum z(x) with rank k is computed and thirdly the normal score transformation of the z-datum with rank k is matched to the percentile groups of the standard normal cumulative distribution function (Deutsch and Jounel, 1998).

Indicator transformation

To characterise the spatial distribution of categorical variables, e.g., soil type, parent material, each datum value z(x) was transformed to an indicator datum I $(x{:}z_k)$ according to:

$$I(x : z_k) = \frac{1, if\ Z(x) \le z_k}{0, if\ Z(x) > z_k} \qquad \text{whereby } k=1,...,N$$

whereby I(x: z_k) was set to 1 if a specific soil type prevails at x, to 0 if not (Deutsch and Journel, 1998).

Standardised semi-variogram

To make semi-variograms comparable, each semi-variogram was standardised by dividing each variogram value by the overall sample variance, whereby the experimental standardised variogram for a separation vector h is computed according to the following formula (Pannatier, 1996):

$$\gamma_s(h) = \frac{\gamma(h)}{\sigma_{-h} * \sigma_{+h}}$$

Local standardisation

For the Warberg data set, fields were found to be significant different with respect to their P concentrations (Chapter 3.3.1). In order to calculate semi-variograms for the entire study site it was necessary to "locally" standardise the data. Local standardisation was carried out by splitting the data into subsets k, whereby subsets were equivalent to fields. For each subset Z-scores with zero mean (μ) and standard deviation (σ) of 1 were calculated:

$$z_{xk} = \frac{x_k - \mu_{x_k}}{\sigma_{x_k}}$$

The semivariograms for Warberg were calculated using the Z-scores.

Detrending

Plots of variogram surfaces were employed to identify spatial trends within the distribution of data. The significance of visually detected trends were statistically tested by plotting the data values against E-W coordinates and N-S coordinates and subsequent calculation of the linear regression. If significant trends were observed ($p \leq 0.05$), semivariograms were calculated on detrended residuals. The residuals were obtained by subtracting the estimated data values obtained from the regression analysis from the original data values (Myers, 2001).

3. Results

The main objective of this research work was to model the spatial dynamics of functional soil P pools. Although, the calculation of experimental variograms and subsequent fitting of appropriate variogram models, is the most common method to model spatial patterns, there is no general agreement on how to evaluate the goodness of the chosen model. There is a tendency within the geostatistic community to justify the choice of a particular model using statistical criteria such as the weighted least-squares criteria (Cressie, 1985), cross-validation (Davis, 1987; Journal, 1987) or the indicative goodness of fit (Pannatier, 1996). The disadvantage of these statistical criteria is that they purely rely on the experimental semi-variogram without taking any ancillary information into account. According to Goovaerts (1997) the "goodness" character of a model is elusive and cannot be measured by rigorous tests.

In the present research work the random function to be modelled is the spatial dynamics of functional P pools, which is represented by the discreet concentrations of the various P species in the soil (Chapter 3.1). Rather than relying on an elusive objectivity of statistical criteria ancillary data such as the chemical parameters of the main soil types (Chapter 3.2), the soil management and the geomorphology (Chapter 3.3) were used to optimise the model parameters of the spatial autocorrelation function of the different P species (Chapter 3.4).

3.1 Phosphorus extracted by different extractants from Kassow, Warberg and Ceveiro

Although there is a considerable disagreement among the geostatistical community how to handle data, that is not normally distributed, the first step when performing geostatistical analysis is to get familiar with the data set by investigating the distribution, as well as analysing the important population parameters (Goovaerts, 1997). Thus, the following chapter presents the results of the descriptive statistics of all P fractions analysed.

In the two soils from the Ceveiro study site 89 % of the samples were below the detection limit of 0.01 mg kg^{-1} with respect to $CaCl_2$ extractable P. Considering the large RSD values for this method (Chapter 2.4, Tab. 2.12) the results were not used for further statistical analysis.

In the two temperate soils $CaCl_2$-P was found to be higher in the Cambisol (Kassow) than in the Luvisol, whereby the variance was higher in the latter (Tab. 3.1). The distribution of

$CaCl_2$-P was not normal in both soils. However, with a skewness of 1.5 for both soils, the data were not strongly skewed (Fig. 3.1).

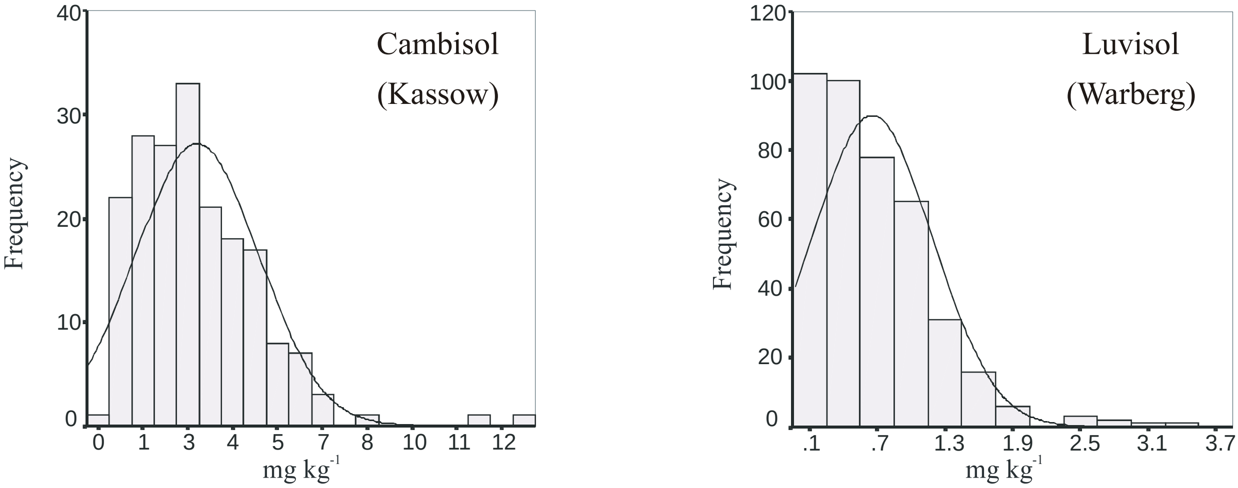

Fig. 3.1: Frequency distribution and summary statistics of $CaCl_2$-P in surface samples (0-20 cm) for the Cambisol (Kassow) and Luvisol (Warberg).

Tab. 3.1: Summary statistics of $CaCl_2$-P in surface samples (0-20 cm) for the Cambisol (Kassow) and Luvisol (Warberg).

Soil	**Min**	**Max**	**Mean**	**Median**	**RSD**
	mg kg^{-1}				**%**
Cambisol	0.21	12.8	3.65	2.78	61
Luvisol	0.15	3.56	0.70	0.60	71

The AAC-P concentration was found to be highest in the Luvisol followed by the Cambisol, the Udorthent and the Paleudult (Tab. 3.2). In non of the soils the P concentration resembled a Gaussian distribution. However, for the Luvisol the AAC-P distribution was found to be close to normality (Skewness = 0.5), whereas it was strongly positively skewed in the Paleudult (Skewness = 6.1). For the Cambisol and the Udorthent the deviation from normality was similar with 2.2 and 2.8, respectively (Fig. 3.2).

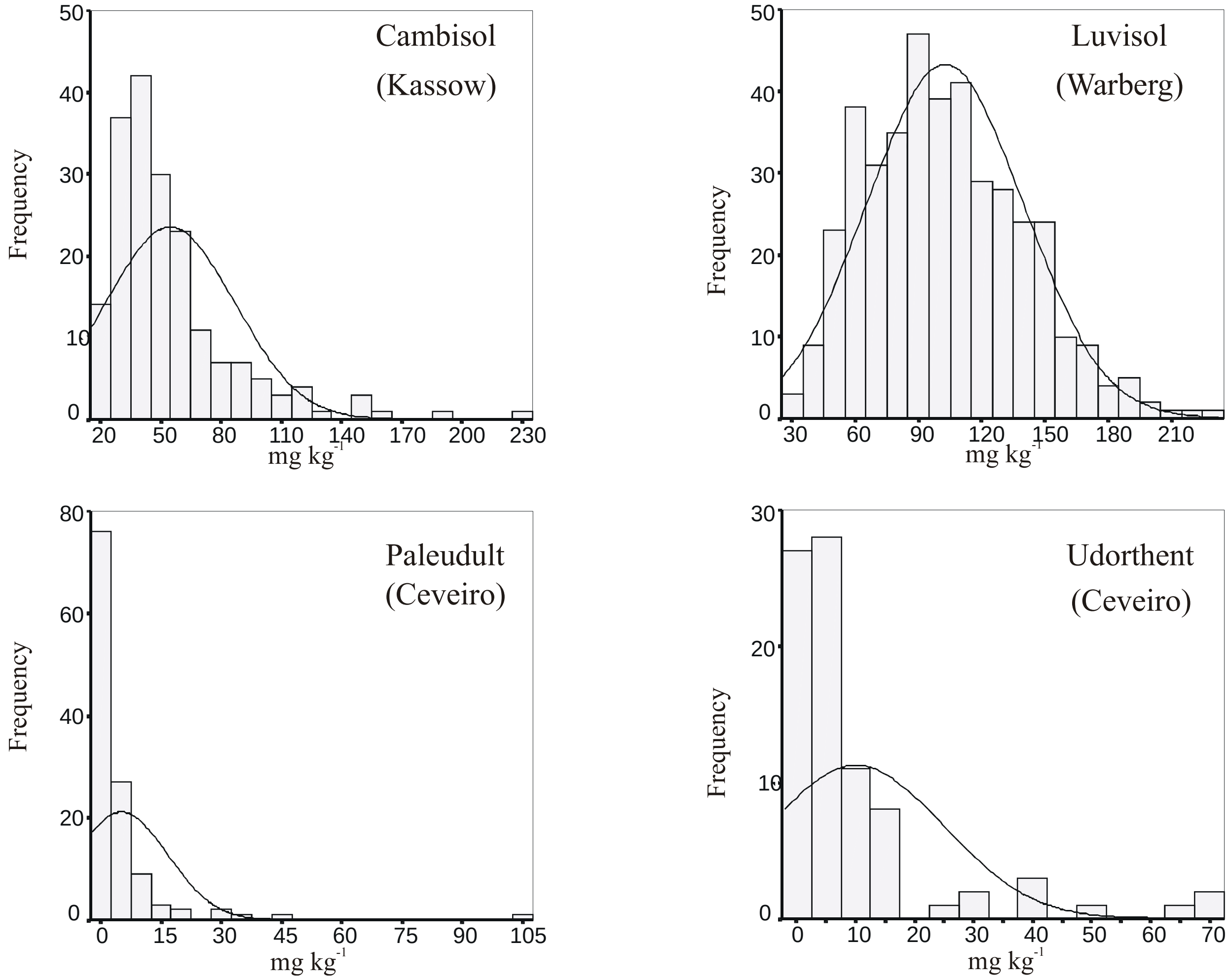

Fig. 3.2: Frequency distribution and summary statistics of AAC-P in surface samples (0-20 cm) for the four different soil types.

Tab. 3.2: Summary statistics of AAC-P in surface samples (0-20 cm) for the four different soil types.

Soil	**Min**	**Max**	**Mean**	**Median**	**RSD**
		mg kg^{-1}			**%**
Cambisol	18.5	228	54.7	45.4	59
Luvisol	28.9	229	102	98.2	36
Paleudult	0.061	105	5.34	1.94	221
Udorthent	0.2	69.8	10.0	3.7	148

In the two tropical soils Resin extractable P resembled the distribution pattern of AAC-P (Fig. 3.3), whereby the median concentration of Resin-P was found to be higher than AAC-P (Tab. 3.3).

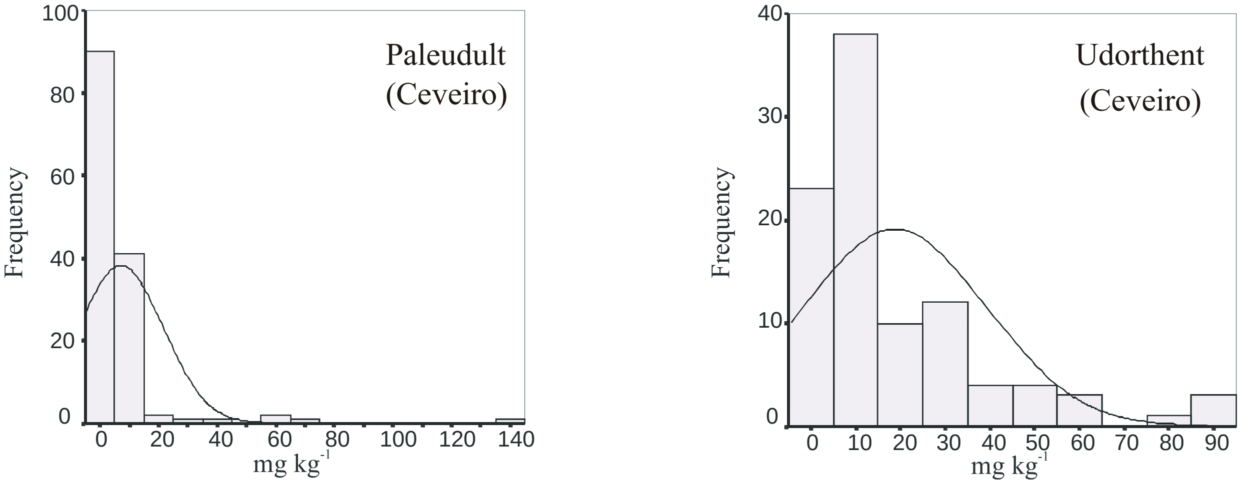

Fig. 3.3: Frequency distribution and summary statistics of Resin-P in surface samples (0-20 cm) for the tropical Paleudult and Udorthent.

Tab. 3.3: Summary statistics of Resin-P in surface samples (0-20 cm) for the tropical Paleudult and Udorthent.

Soil	**Min**	**Max**	**Mean**	**Median**	**RSD**
		mg kg^{-1}			**%**
Paleudult	1.00	136	8.45	4.00	193
Udorthent	2.0	92	18.7	10.0	109

The medial concentrations of WH-P and AR-P were found to be lowest in the Paleudult and increased from the Udorthent, over the Luvisol to the Cambisol, whereby the concentration in AR-P was at least four times higher in the two temperate soils than in the Paleudult (Tab. 3.4 & Tab. 3.5). With the exception of AAC-P in the Luvisol the distribution of AR-P was found to have the lowest skewness in all soils when compared to the distribution of the other P fractions (Fig. 3.5).

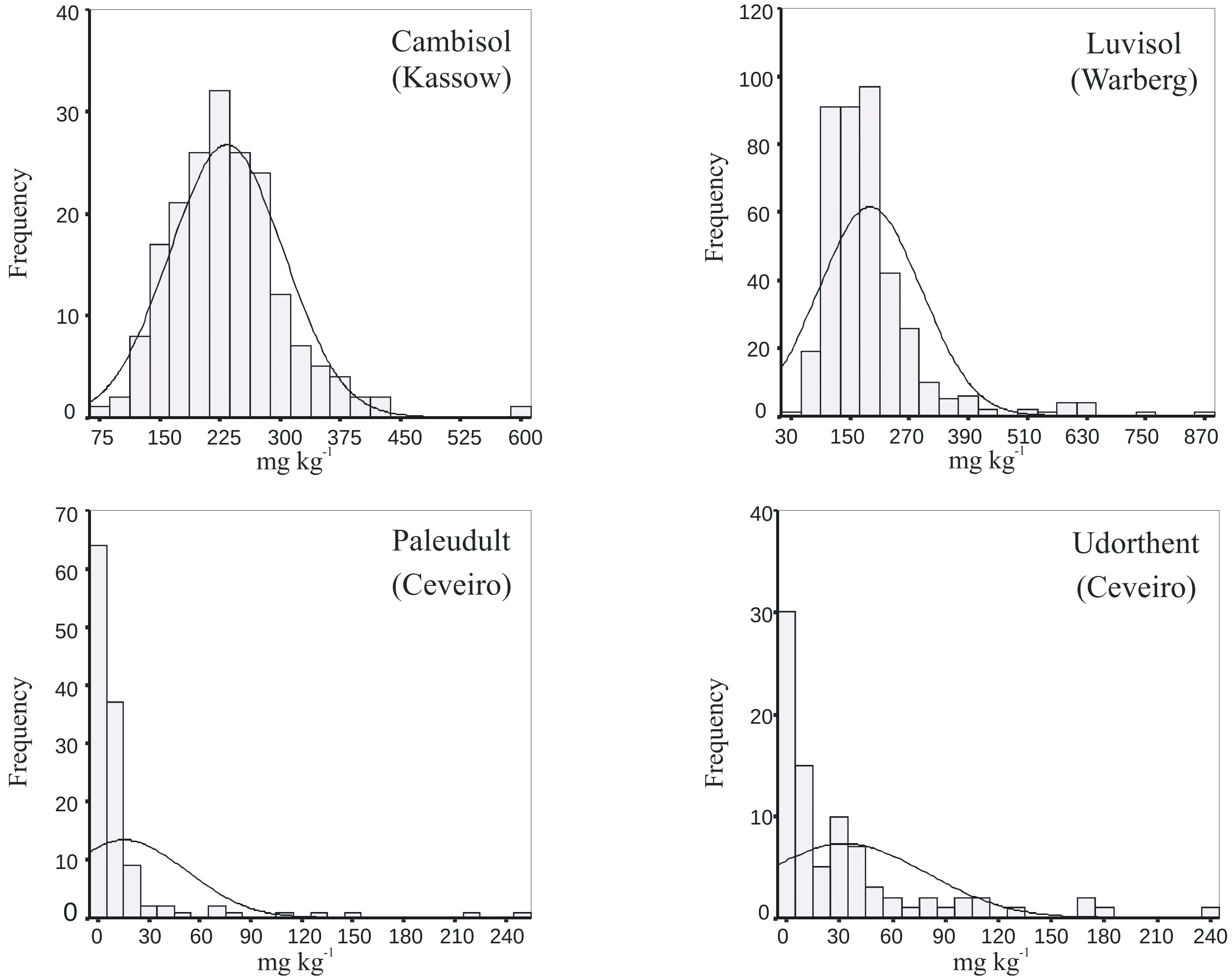

Fig. 3.4: Frequency distribution of WH-P within surface samples of the Cambisol, Luvisol, Paleudult and Udorthent.

Tab. 3.4: Summary statistics of WH-P in surface samples (0-20 cm) for the four different soil types.

Soil	**Min**	**Max**	**Mean**	**Median**	**RSD**
	mg kg^{-1}				**%**
Cambisol	83.6	596	324	228	30
Luvisol	23.8	869	190	171	55
Paleudult	0.010	248	16.18	4.36	231
Udorthent	0.4	239	32.9	12.9	141

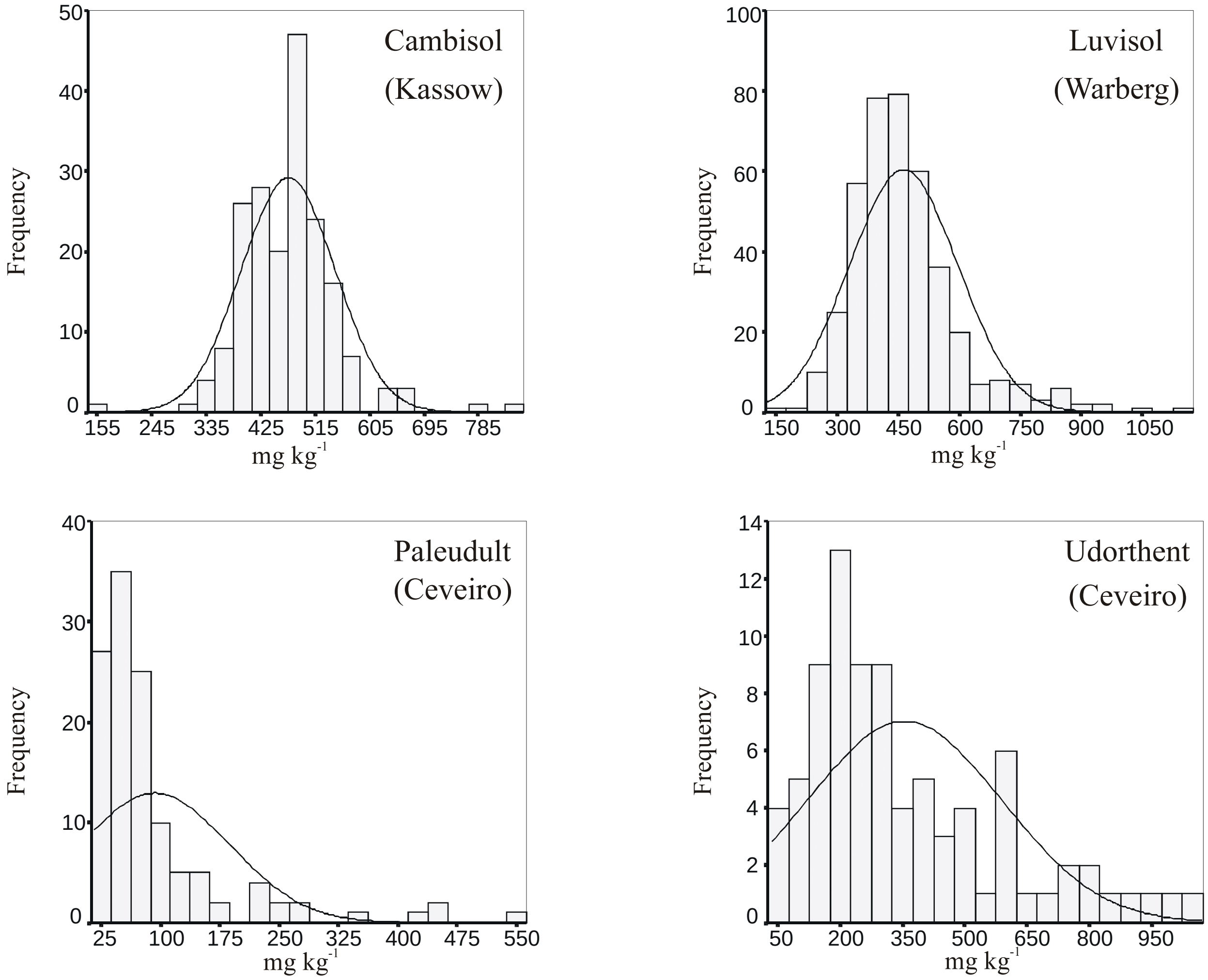

Fig. 3.5: Frequency distribution and summary statistics of AR-P in surface samples (0-20 cm) of the four different soil types.

Tab. 3.5: Summary statistics of AR-P in surface samples (0-20 cm) for the four different soil types.

Soil	**Min**	**Max**	**Mean**	**Median**	**RSD**
	mg kg^{-1}				**%**
Cambisol	157	835	471	474	17
Luvisol	151	1150	463	441	29
Paleudult	15.1	553	94.7	59.7	101
Udorthent	33.5	1041	354	281	66

3.2 Chemical speciation of phosphorus at Kassow, Warberg and Ceveiro

Speciation can be defined either functionally, operationally, or as specific chemical compounds or oxidation states (Ure and Davidson, 1995). As this work is a contribution to the knowledge of spatial P dynamics in order to improve P management strategies, here speciation is used functionally, considering the strength of the bonding between phosphorus and soil particles as an indication of its plant availability, as well as its mobility. In the following chapter the partitioning of the soil P continuum into different functional pools is investigated for each soil type. The investigation is based on the extraction force of $CaCl_2$, Resin, AAC, WH, and AR, as well as the bivariate relation between the individual P fractions.

3.2.1 Allocation of extraction methods to functional P pools

In the previous methodological investigation it was shown that $CaCl_2$, AAC, and AR differ significantly in their extraction force when homogenised reference material was used (Chapter 2.4.2, Tab. 2.13). However, as the reference material represents only the average soil properties of the study sites it was necessary to test the hypothesis that selected extractants differ with respect to their extraction force for all soil samples. The Kruskall-Wallis test (SPSS, 1998) comparing the medial P concentrations extracted by the different methods showed that for the two temperate soils all four methods differed significantly with respect to their extraction force, whereas in the tropical soils no difference with respect to their extraction force was found for Resin, AAC, and WH (Tab. 3.6).

Tab. 3.6: Comparison of the medial extraction force (%) of extraction methods used, when compared to AR (100 %), for the main soil types.

Soil	**Method**			
	Resin	**$CaCl_2$**	**AAC**	**WH**
Cambisol (Kassow)	n.a.	0.6	9.5	48.1
Warberg (Warberg)	n.a	0.1	22.3	38.8
Paleudult (Ceveiro)	5.6	bdl.	8.9	17.1
Udorthent (Ceveiro)	2.8	bdl.	5.9	9.3

n.a.= not available; bdl. = below detection limit (< 0.01 mg kg^{-1})

From the above results it can be derived that for the temperate soils, the Cambisol (Kassow) and the Luvisol (Warberg), P fractions, extracted by the different extraction methods, differ in their plant availability and as such are representative of four functional P pools. For the two tropical soils, the Paleudult and the Udorthent, Resin, AAC and WH appear to extract P fractions with a similar solubility and therefore plant availability and are suggested to represent the same functional pool. That implies that in the tropical soils the soil P continuum comprises only two of the proposed functional pools.

3.2.2 Partitioning of soil P between the different extractants

The speciation of soil P into pools of different plant availability, so called functional P pools (Guo and Yost, 1998, Chapter 4.1) can either occur as molecular speciation, which is a function of thermodynamic and kinetic properties of the chemical reactions between P and soil particles or by differentiated distributions among soil components, such as organic matter or hydrous oxides. In the first scenario, the spatial speciation is assumed to be low, as P is retained with different energy within the different soil compounds, but they tend to be in equilibrium among themselves and with the soil solution. Their solubility is supposed to be just a function of the particular extraction solution used (Simonis, 1996). In the second scenario, the spatial speciation is assumed to be more pronounced as the distribution of different soil components with a particular bonding energy for P will result in a spatial differentiation of P species.

First indication for the occurrence of spatial speciation is therefore the bivariate relation of P extracted by different extractants. If the P concentrations of two extractants show a large degree of covariance, it is suggested that the corresponding pools are in equilibrium with each other. According to the SPSS regression analysis, all P fractions, extracted from each soil type, were found to be highly significantly ($p < 0.001$) correlated. However for the purpose of this work two P fractions and their corresponding pools were only assumed to co-vary when their correlation coefficient was at least 0.7 ($R^2 \geq 50$ %).

As the correlation coefficient r is strongly affected by extreme values, the rank coefficient r_s was used. However, a comparison of the two provides important information about irregularities within the relation of the two P fractions under investigation, whereby $r > r_s$

indicates the presents of extreme values and $r_s > r$ values with a high y deviation from the regression line.

For the Cambisol (Kassow) r and r_s were not significant different (Fig. 3.6). AAC-P and WH-P explained only 21 % and 29 % of the variation in $CaCl_2$, respectively. It is therefore concluded that most of the P extracted by AAC and WH was not associated with a larger concentration of P extracted by $CaCl_2$. The low correlation between AAC-P and AR-P suggested further that the increase in AAC-P was independent of an increase in AR-P. However, WH-P, which was found to increase with increasing AR-P, explained more than 50 % of the variation in AAC-P. Additionally, it could be shown that the occurrence of carbonates did not influence the correlation between the P concentrations (Fig. 3.6).

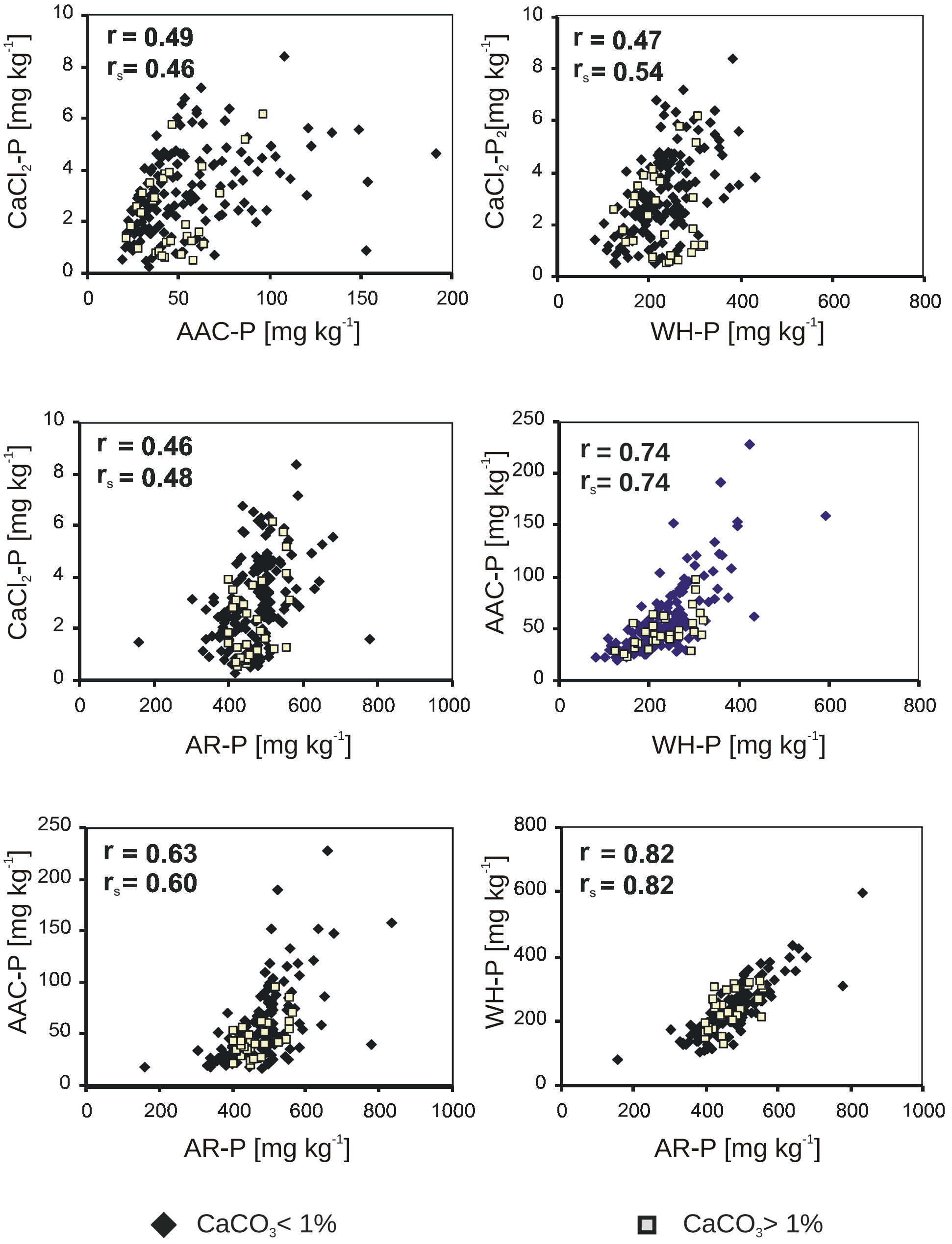

Fig. 3.6: Scatterplot and regression coefficients for P in different extracts in soil samples from Kassow (r = correlation coefficient, r_p = rank correlation coefficient).

For the Luvisol (Warberg) large differences between r and r_S were found (Fig. 3.7). Dividing the soil samples into two groups, calcareous and non calcareous, revealed that the deviation of the two correlation coefficients was mainly caused by the latter. The correlation between AR-P and WH-P was stronger for samples with a high $CaCO_3$ content (> 1 %) than for ones with a low content. In comparison the correlation between AAC and either AR-P or WH-P decreased with increasing $CaCO_3$ content of the soil samples. Whereas, the correlation between $CaCl_2$-P and AAC-P and AR-P was not effected by the presence of $CaCO_3$, it was weakened between $CaCl_2$-P and WH-P.

Based on the overall r_s only AAC-P and WH-P were found to have a high covariance, whereby AAC-P increased with increasing WH-P. None of the other P fractions was found to co-vary.

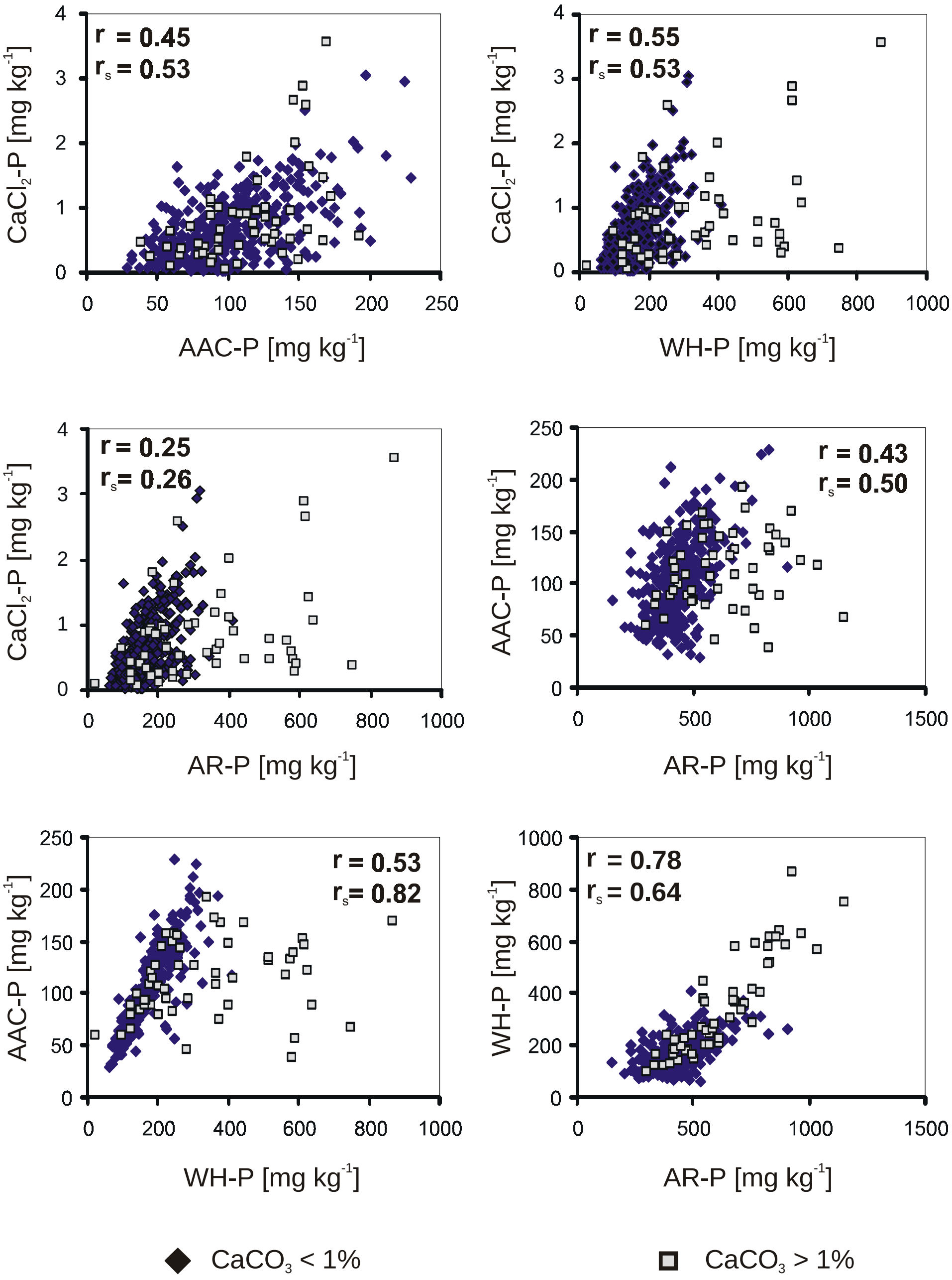

Fig. 3.7: Scatterplot and regression coefficients for P in different extracts in soil samples from Warberg (r = correlation coefficient, r_p = rank correlation coefficient).

For the two temperate soils the results suggest that within the Cambisol from Kassow a special speciation of P with respect to its $CaCl_2$, AAC and AR extractable fraction occurred. Whereas WH-P was expected to have a similar distribution as AR-P. In the Luvisol from Warberg the strong impact of the carbonate content on the extraction force of the extractant used, camouflaged the relationship of the different P fractions. Therefore, the analysis of the bivariate relationship between the different P fractions did not reveal explicit information on the degree of the spatial speciation of P within the Luvisol.

In the Paleudult the bivariate relation between P in different extracts was generally poor. Only AAC-P and WH-P were found to co-vary. For all pairs r was found to be higher than r_s. As all of these extreme values originate from soil samples collected under sugar cane it is suggested that these high concentrations are associated with P fertilisation. This implication seams to be supported by the finding that the P concentrations of these samples was relatively lower in AR than in the other extraction methods, which implies that these high P concentrations displayed a high solubility and therefore are likely to be caused by high soluble fertiliser sources (Fig. 3.8).

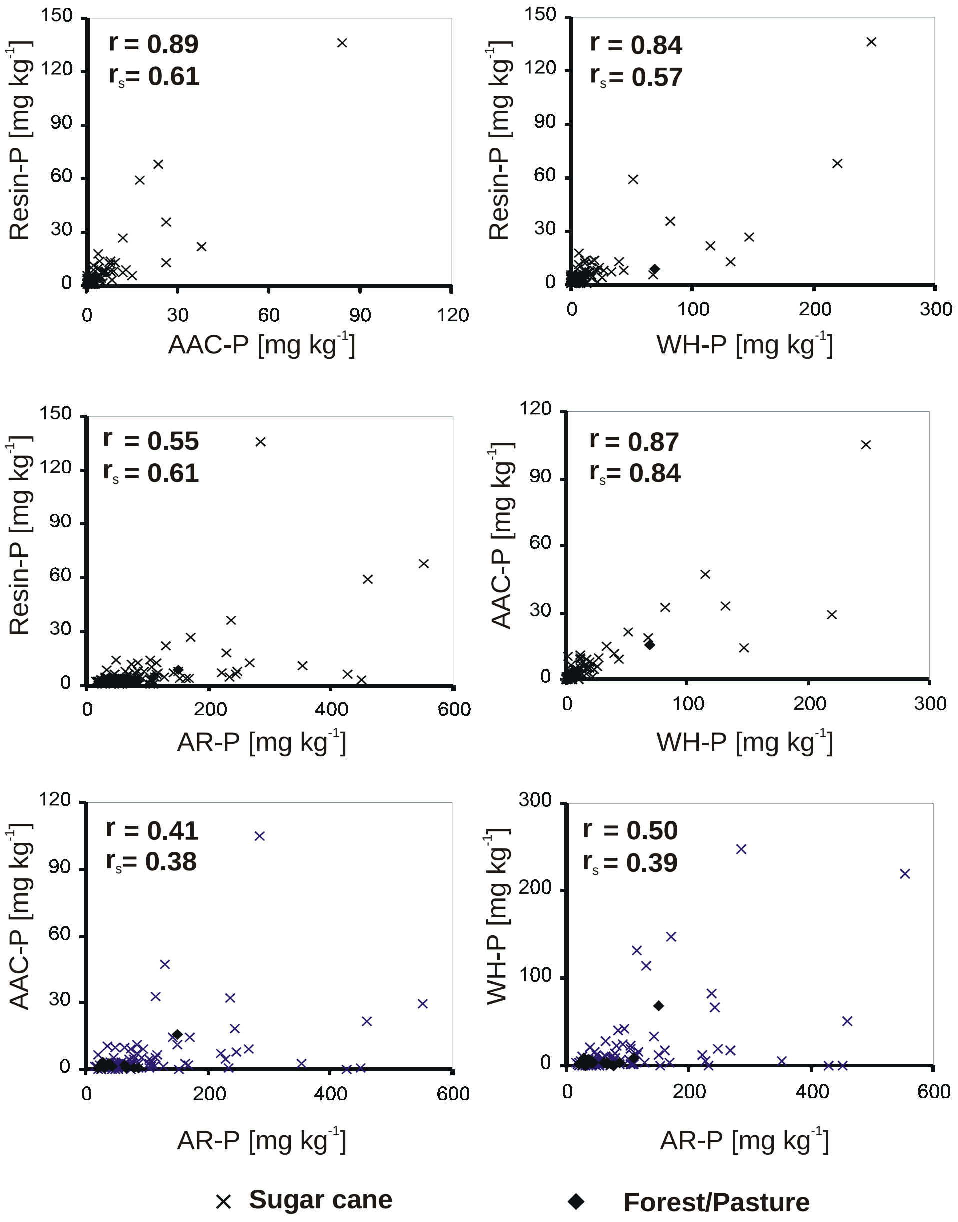

Fig. 3.8: Scatterplot and regression coefficients for P in different extracts in an arenic Paleudult from Ceveiro (r = correlation coefficient, r_p = rank correlation coefficient).

In the Udorthent the differences between the two correlation coefficients were not as distinctive as in the Paleudult. Although Resin-P was found to increase with increasing AR-P, AAC-P and WH-P were found to be independent of AR-P. AAC-P was found to co-vary with WH-P and Resin-P (Fig. 3.9).

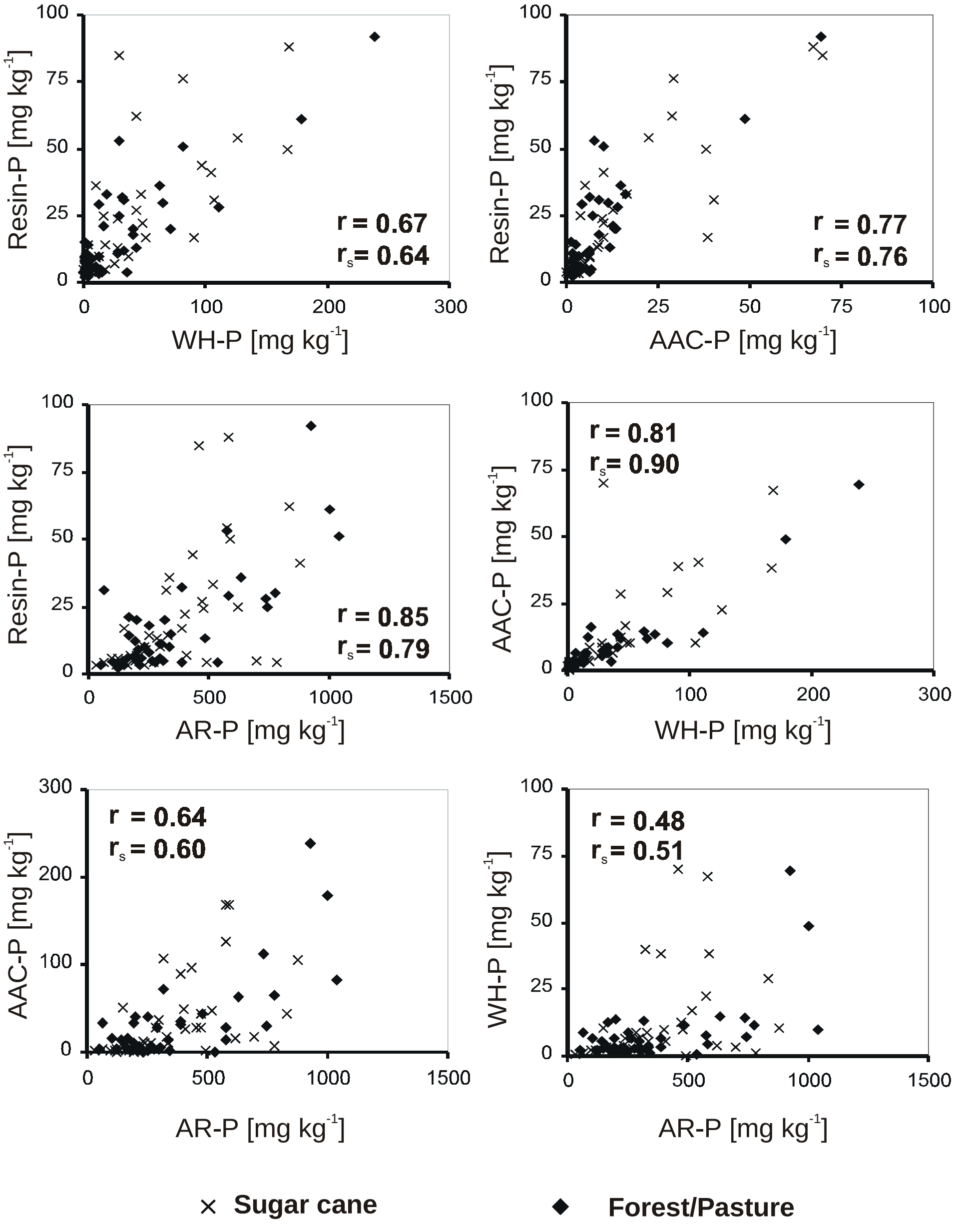

Fig. 3.9: Scatterplot and regression coefficients for P in different extracts in a typic Udorthent from Ceveiro (r = correlation coefficient, r_p = rank correlation coefficient).

For the two tropical soils, the Paleudult and the Udorthent, the results revealed that AAC, Resin and WH extract P from the same functional pool (Chapter 3.2.1). The overall poor correlation between these fraction in particular in the Paleudult indicate that the reversibly available P pool is not very homogeneous, but consists of a variety of P species. Although, Resin-P displayed a comparatively strong correlation with AR-P, it is suggested that within the tropical soils a spatial speciation between the reversibly available and the sparingly available P pool occurred.

3.2.3 Identification of soil parameters that relate to the speciation of soil phosphorus

This chapter presents the results of the statistical analysis of interactions between different P species and their reaction with main soil chemical properties. In the previous chapter it was demonstrated that a significant correlation between the individual P fractions occurred. Multivariate analysis of a complex set of soil parameters is often flawed due to high correlation among/between the variables. Part of the problem is that the value of the regression coefficient for one variable changes depending on what other variables are used in the equation (Mallarino et al*.,* 1999). Moreover, tests of significance of the coefficients become unreliable when variables are highly correlated (Bowerman and O'Connell, 1990).

Principal Component analysis (PCA) circumvents the problem of multicollinarity. The idea behind PCA is to group variables so that the correlation of two variables from different groups is small and that for two variables of the same group is large. Each group can be represented by a new variable that is created from the variables in the group, the so-called latent variable. The interpretation of the latent variable, which is the underlying factor that causes the variables of one group to co-vary, is the most crucial part of the PCA (Schnug, 1985). In Chapter 3.2 the main factors governing the crop availability of soil P, intensity, quantity and capacity, were introduced.

For the interpretation of the PCA only Principal components (PC) with an Eigenvalue > 1 (Chapter 2.6.1) were retained. For the Cambisol (Kassow) 60 % of the variance was explained by the first two PCs, whereby the PC1 accounted for 41 % and the PC2 for 19 % of the total variability explained by the model. The results are summarised in Fig. 3.10, whereby the relative position of the variables along the axis is equivalent to their rotated loadings on the corresponding PC (see also Appendix, Tab. A.10). High loadings (> 0.49) on PC1 were found for all P species as well as Zn. Because of the collective co-variance of this group of variables PC1 can be interpreted as "the quantity factor" (PC1), which is dependent on the one hand by the low adsorption capacity (capacity factor) of the sandy Cambisol and on the other by the input of P in form of mineral fertiliser. PC2 was highly loaded (> 0.49) by pH, C_{tot} and $CaCO_3$. With the exception of $CaCl_2$-P which displayed a negative loading on PC2 this group was not correlated with any of the P species. The lack of natural calcite in the Cambisol suggests that this group of variables is affected strongly by the application of lime. The negative loading of $CaCl_2$-P on PC2 is thought to be caused by the negative correlation between the clay content of the soil and $CaCl_2$-P.

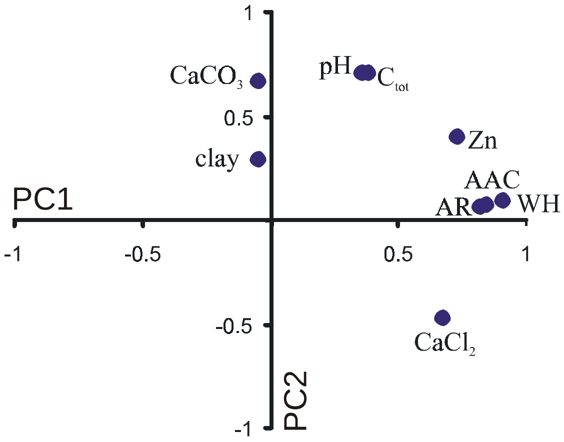

Fig. 3.10: Plot of the rotated component matrix for soil parameters of a Cambisol from Kassow.

For the Luvisol (Warberg) three PCs explained 73 % of the total variability observed within the data set. The rotated factor loadings are illustrated in Fig. 3.11. C_{tot}, $CaCO_3$,WH-P and AR-P were found to have a high correlation with the PC1 which accounted for 42 % of the total variance. Based on this the latent variable of this group was interpreted to be secondary Ca-phosphate minerals in the soil. PC2, which explained 18 % of the variance was collectively explained by clay, Fe, AR-P, Zn and soil pH. $CaCl_2$-P was found to be negatively correlated with this group. The underlying factor that is governing the covariance of this group is suggested to be the adsorption capacity of the soil. PC3, which accounted for 13 % of the total variance, was found to be highly correlated with $CaCl_2$-P and AAC-P. Although, AR-P and WH-P were also positively correlated with PC3, the correlation was not significant. The observed partitioning of the P fractions, where AR-P and WH-P group together with $CaCO_3$ and C_{tot} loading high on PC1 and AAR-P and $CaCl_2$-P forming a separate group is likely to be caused by the low extraction force of the two latter methods for soil samples with a high carbonate content (Chapter 3.2.2).

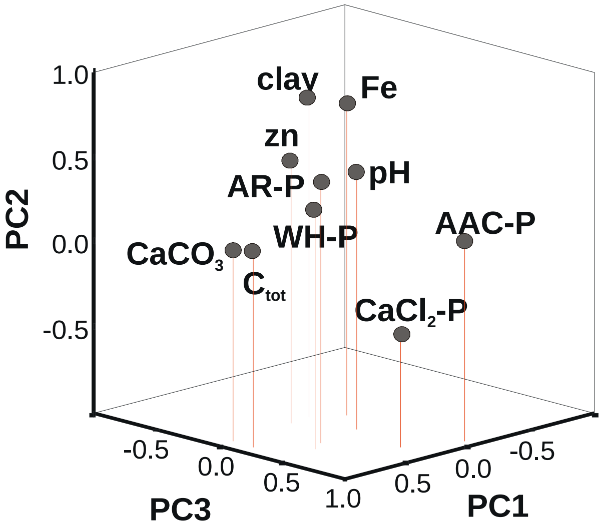

Fig. 3.11: Plot of the rotated component matrix for soil parameters of a Luvisol from Warberg.

For the two main soil types in Ceveiro, the results of the factor analysis showed similar results. In both soils two PCs were identified, explaining 65 % and 71 % of the total variation observed for the variables analysed in the Paleudult and Udorthent, respectively. In both soils high loadings on PC1, explaining 47 % in the Paleudult and 42 % of the total variance in the Udorthent were found for Zn, clay, Fe and AR-P. The latent variable for these groups was interpreted to be the specific adsorption capacity of the soils for P, which is most likely to be the presence of Al- and Fe-oxides (Chapter 2.1.2). The variation of P extracted by AAC, WH and Resin was explained by PC2, accounting for 18 % in the Paleudult and 29 % of the total variance in the Udorthent. The latent variable of this group is interpreted as P input, either in form of fertiliser amendment, or chemical weathering of apatite. The plot of the rotated component matrix shows that the division of the two P pools is stronger in the Udorthent than in the Paleudult (Fig. 3.12a and b).

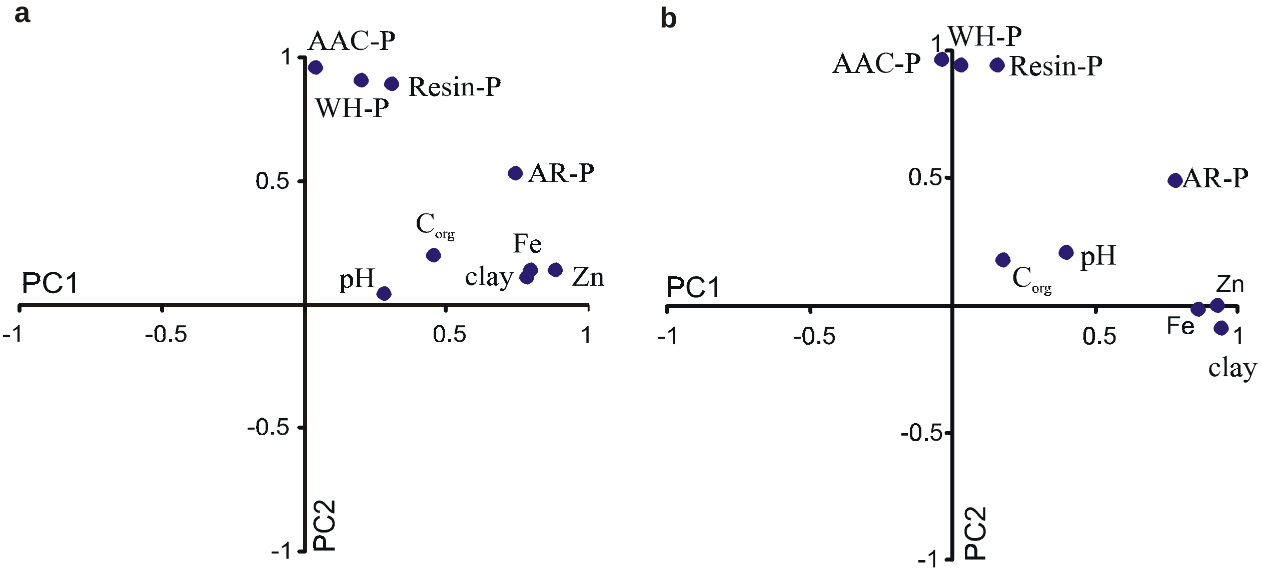

Fig. 3.12: Plot of the rotated component matrix for soil parameters of a arenic Paleudult (a) and a typic Udorthent (b) from Ceveiro

The results of the principal component analysis revealed that the dominant factors controlling chemical speciation of P were: the “quantity” factor and the application of lime in the Cambisol (Kassow); secondary Ca-phosphate minerals and the “capacity” factor in the Luvisol (Warberg); the “capacity” factor and P input (Fertilisation, weathering of apatite) in the two tropical soils, the arenic Paleudult and the typic Udorthent (Appendix, Tab. A.10). The chemical speciation resulted in a strong partitioning of the functional soil P Pools in Warberg and Ceveiro, but not in Kassow.

3.3 Anthropogenic and geogenic factors that control the speciation of soil P

As outlined in the previous chapter one of the objectives of this research work was to test the hypothesis that the spatial distribution of soil P species is related to site specific environmental factors. The aim of this chapter is to qualify the anthropogenic and geogenic factors that result in a spatial speciation of P. This was done by employing a multivariate GLM procedure which provides regression analysis and analysis of variance (ANOVA) for multiple dependent variables by one or more factor variables or covariates (Chapter 2.6.1). Firstly, the overall significance of the GLM for the individual P fractions and study sites is presented, followed by a detailed analysis of the separate factors and covariates used in the respective GLM procedure (see Appendix, Tab. A7– A.9).

For the two temperate sites, Kassow and Warberg, the overall correlation between the P concentrations estimated by the GLM model and the measured P concentrations was low. In Kassow the GLM explained 36 % of the variation in $CaCl_2$-P, 8 % of the variation in AAC-P, 26 % of the variation in WH and 23 % of the variation in AR-P. Similar results were obtained for Warberg, with the GLM explaining 35 % of the variation in $CaCl_2$-P, 24 % of the variation in AAC-P, 31 % of the variation in WH and 23 % of the variation in AR-P. In Ceveiro a good correlation was found between estimated and measured AR-P concentrations, whereby the GLM explained 62 % of the variation.

3.3.1 Fertilisation

Kassow

The effect of fertilisation on the different P fractions could be tested directly for Kassow and Warberg. In Kassow variable rate P-fertiliser was applied 12 and 24 month prior to sampling. The fertiliser loads were estimated by retrieving the fertiliser rates for each sampling point from the variable rate fertiliser application map (Chapter 2.1.1, Fig. 2.4) and used as a continuos variable in the GLM. The solutions of the random effects (Appendix, Tab. A.23-A.26) revealed that fertilisation was highly significant for the distribution of all P fractions within the Cambisol in Kassow. However, for AAC-P, which is representative of the readily plant available P pool, the significance of fertilisation was an order of magnitude lower than for the other fractions (Appendix, Tab. A.23-A.26). Considering that the variable rate fertilisation was aimed at balancing out the natural variation of the readily plant available P pool, a successful fertiliser regime would result in zero correlation between applied fertiliser and soil P concentration. It is suggested therefore that the lower p-value of the covariate “fertilisation” and the overall low fit of the GLM for AAC-P indicate that the bioavailable P pool was stronger effected by the variable rate fertiliser regime than the other P pools.

Warberg

In Warberg the latest mineral fertiliser application took place three years prior to sampling. However, recent manure application were evident on field GB at the time of sampling. As records of fertiliser application in particular application of swine manure were not available, P application rates could not be quantified for the entire study site. However, it was assumed that the average P concentrations of the individual fields was the result of a continuous accumulation of applied P that was not removed by plans. Field-type, was therefore, used as a factor variable indicating the effect of P application on the distribution of different P fractions.

For all methods used highest P concentrations was found in soil samples from field BB, followed by M3, GB, M2 and M1, respectively (Fig. 3.13, see also Chapter 3.3.3, Tab. 3.7). The statistical significance of the difference between the fields was confirmed by the overall model F test for $CaCl_2$-P and AAC-P, but not for WH-P and AR-P (Appendix, Tab. A.36-A.39). However, the individual tests showed that the low average P concentrations in M1 and M2, when compared to the other fields, was significant for all P fractions (Appendix, Tab. A.15-A.18). In addition, it could be shown that these lower P concentrations were not caused by differences in soil texture, as the interaction of field type and soil type was not found to be significant for any P fraction (Appendix, Tab. A.36-A.39).

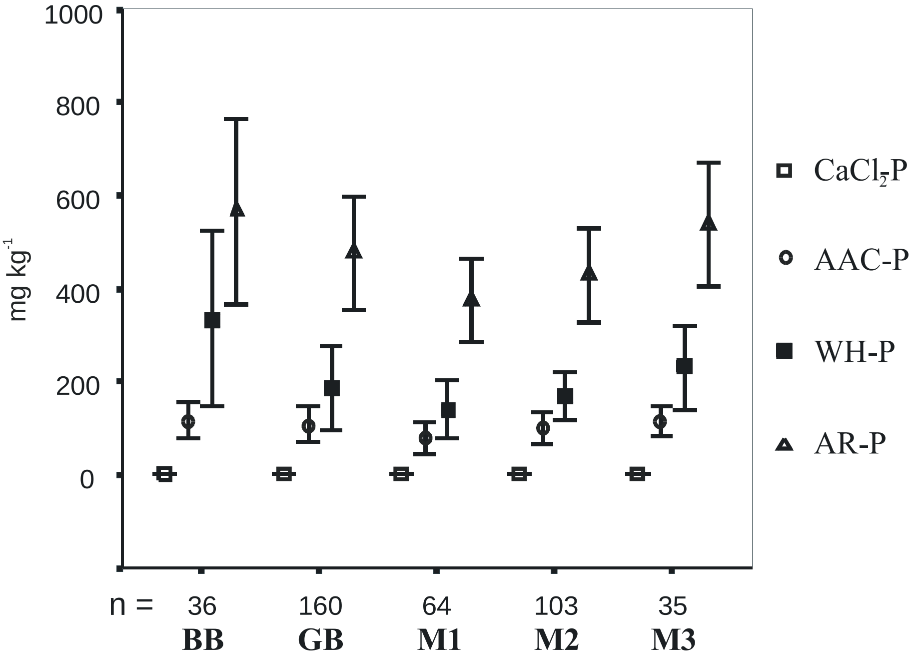

Fig. 3.13: Comparison of the average P concentrations in $CaCl_2$, AAC, WH and AR for individual fields at Warberg. Error bars indicate standard deviations.

Ceveiro

For Ceveiro, neither records of P fertiliser rates, nor borders of individual fields were recorded. However, within the Ceveiro watershed areas of different land-use can be characterised according to their P input. Sugar-cane was classified as area of high P-input, whereas pasture and forest are areas of low-P input. To sugar cane P is applied as mineral fertiliser as well as organic P in form of crop residues; to pastures and forests P is added as manure and/or with sedimentation in form of particulated P (Gassner et al., 2002b). The factor land-use, was therefore, used as an indicator of the impact of anthropogenic P input on the distribution of soil P fractions in Ceveiro.

For AAC-P, Resin-P and WH-P lowest average concentrations were found in soil samples collected under forest, whereas lowest AR-P concentrations was estimated for soil samples collected under sugar cane (Fig. 3.14).

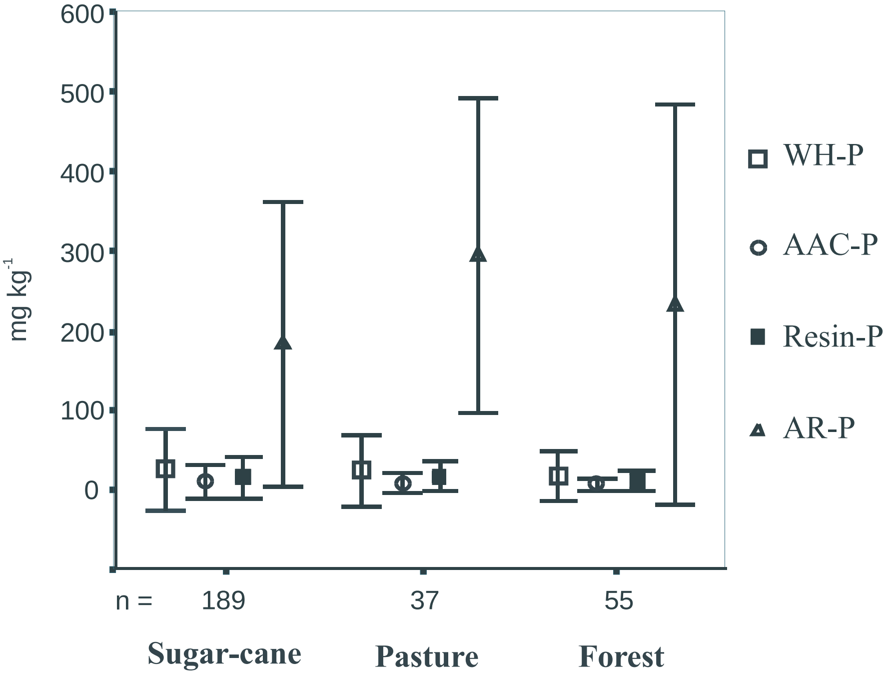

Fig. 3.14: Comparison of the average P concentrations in AAC, WH, Resin and AR for different land-uses in Ceveiro. Error bars indicate standard deviations.

After transformation of the data the GLM revealed that the observed differences between land-uses in Ceveiro with respect to their average P fractions was not statistically significant (Appendix, Tab. A.40-A.43).

The GLM procedure revealed that in Kassow fertilisation was the dominant factor controlling the distribution of P pools. Although the reversibly available P pool was less strongly affected by fertilisation the overall effect has to be regarded as similar for all pools. In contrast, at the Warberg study site fertilisation was found to effect only the readily and the reversibly available P, but not the sparingly available P pool. At the Ceveiro study site, no significant impact of land-use and thus, anthropogenic P input, was found. However, under areas of high P-input, sugar cane, the sparingly available P pool was found to be lower than in areas of low input.

3.3.2 Parent material

Parent material influences the speciation of soil P in two ways: the retention of P by soil is mainly controlled by the specific adsorption capacity of soil particles which is a function of their specific surface area (Schwertmann and Taylor, 1998) and as such is strongly dependent of the soil texture; in young soils the weathering of P-minerals, such as apatite, can significantly control the P concentration in the soil solution (Scheffer and Schachtschabel, 2002).

Kassow

The northern German till plains gave rise to extremely heterogeneous soils (Zarncke, 1989). Although, the Cambisol at Kassow can on average be characterised as having a very light texture, the study site displayed a considerable variation in the silt content of the soil (Chapter 2.1.1, Fig. 2.3). A comparison of the average P concentrations between the different soil texture classes revealed that for WH-P ($p < 0.02$) and $CaCl_2$–P ($p < 0.01$) the texture classes differed significantly, whereas not for AR-P and AAC-P (Appendix, Tab. A.11-A.14). The average P concentration in $CaCl_2$ was found to decrease with increasing percentage of silt, whereby the P concentration for sandy loam (sL) and high loamy sand (SL3) were significantly lower than in loamy sand (lS) and medium loamy sand (Sl3) (Fig. 3.15). For WH-P the relationship between extracted P and soil texture was not that clear, but the individual tests showed that the average P concentration in sandy loam (sL) was significantly lower than in the other three texture classes (Appendix, Tab. 12).

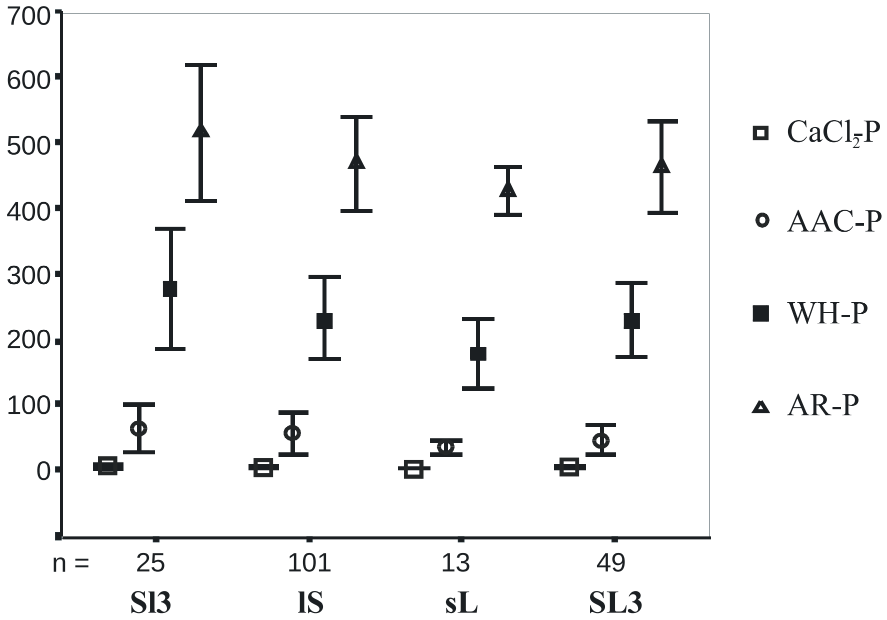

Fig. 3.15: Comparison of the average P concentrations in $CaCl_2$, AAC, WH and AR for soil texture classes at Kassow. Soil texture classes were assigned based on the Reichsbodenschaetzung for Kassow (Mueckenhausen et al., 1988).

Warberg

In contrast to the till plains, loess derived soils of the Boerde landscape are supposed to be some of the most homogeneous soils in Germany (Altemueller, 1957). Rather than parent material, geomorphology plays an important role in the pedogenesis of loess derived soils (see next Chapter). In Warberg soil texture classes were found not to differ significantly with respect to their $CaCl_2$-P, AAC-P and WH-P fractions (Appendix, Tab. A.36-A.39). However, the concentration of AR-P was found to be significantly ($p = 0.05$) lower in the loamy soil than in the clayey soil (Appendix, Tab. A.36).

Ceveiro

With respect to the parent material Ceveiro has to be regarded the most complex of the three study sites. Fourteen different soils are derived from three lithostratographic units dating from the Paleozoic to Cenozoic eras (Simões et al., 2000). The floor of the basin and parts of the northfacing hills are formed by limestones, siltstones and shales of the late Permian Corumbataí formation, and the southfacing slopes by sandstones and claystones of the Pirambóia formation. Both formations are intruded by basaltic dykes of the Serra Geral formation (Sparovek, 2000). Due to the random sampling (Chapter 2.2.2, Appendix, Fig. A.3) and the patchy distribution of soil types within the study site (Fig 2.11) eleven of the soil types found, were only represented by less then 5 % of the total samples. As it was not possible to retrieve a GLM using all fourteen soil types these eleven soil types were grouped together to form one class. As the main soil types represented the two most extreme soils with respect to their weathering stages, with the arenic Paleudult displaying the lowest anion absorption capacity and the typic Udorthent the highest, it was assumed that by grouping the minor soil types together no significant information was lost.

For AAC-P, Resin-P and WH-P, soils developed on the Piramboia formation were found to have the highest average P concentrations, followed by soils developed on the Corumbatai and the Serra Geral formation, respectively. For AR-P the reversed order was found, with the highest average P concentration occurring in soils derived on the younger basaltic Serra Geral formation and the lowest in soils developed on the Piramboia formation (Fig. 3.16).

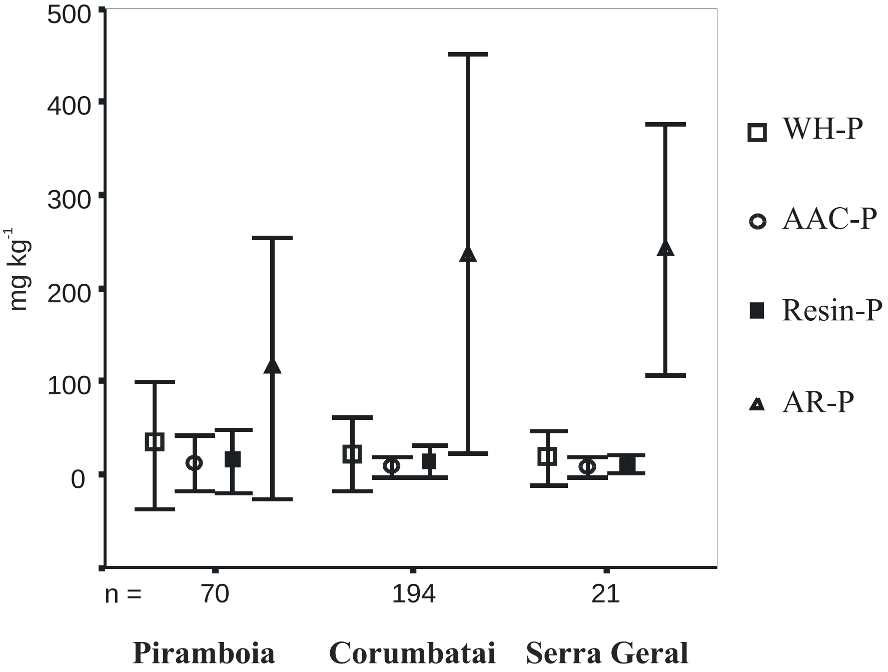

Fig. 3.16: Comparison of the average P concentrations in AAC, WH, Resin and AR for different parent materials in Ceveiro. Error bars indicate standard deviations.

The GLM procedure revealed that the differences between types of parent material were significantly different for AAC-P, WH-P and AR-P. A comparison of the p values showed that parent material had a stronger effect on the distribution of AR-P than on the distribution of

AAC-P and WH-P. No significant differences were found for Resin-P (Appendix, Tab. A.40-A.43).

The average AR-P concentration was found to be significant lower in the arenic Plaeudult than in the other soil types (Appendix, Tab. A.19). Highest AR concentration were found for the typic Udorthent (Fig. 3.17). Highest concentrations of AAC-P, WH-P and Resin-P were analysed in the typic Paleudalf. Whereas this difference to the other 3 soil types was found to be significant for AAC-P and Resin-P, it was not significant for WH-P (Appendix, Tab. A.40-A.43). The interaction of parent material and soil type was not found to be significant for the distribution of any of the P fractions.

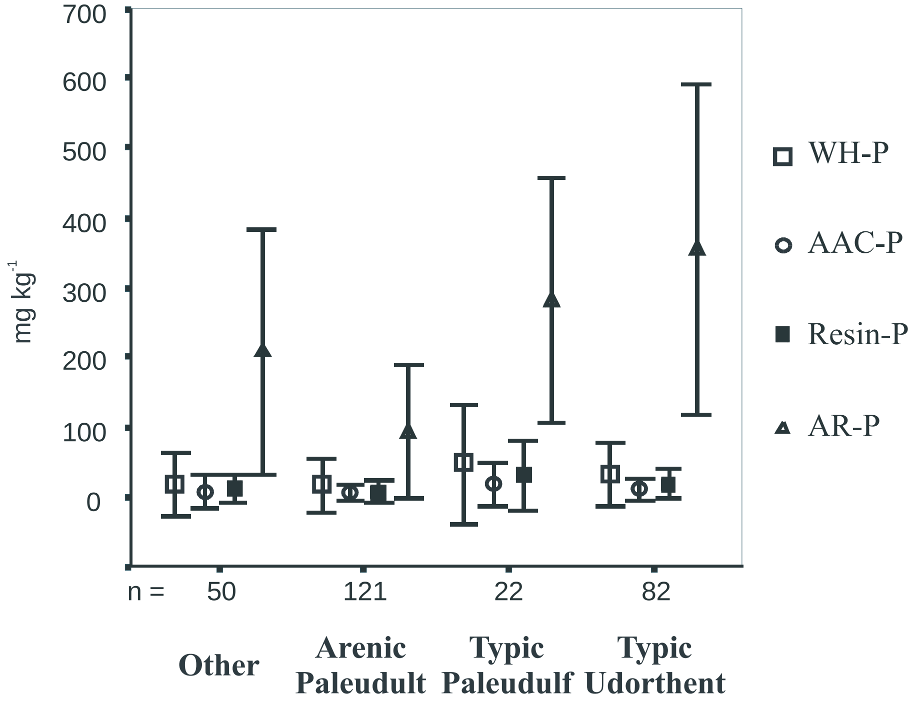

Fig. 3.17: Comparison of the average P concentrations in AAC, WH, Resin and AR for different soil types in Ceveiro. “Others” consists of 14 soil types each accounting for less than 5 % of the samples.

Parent material, in the form of soil texture was found to control the spatial speciation of P pools in both temperate study sites. In the sandy Luvisol (Kassow) soil texture was found to control the distribution of $CaCl_2$-P and WH-P. In contrast, in the clayey Loess derived soil (Warberg) only the sparingly available P pools was affected by soil texture.

In the tropical soils parent material was found to be an important factor controlling the distribution of individual soil P pools within the Ceveiro study site. The effect was mainly caused by the presents and weathering of primary P-minerals, reflected in a higher sparingly available P concentration in the younger geological formations as well as in the less weathered soil types.

3.3.3 Geomorphology

Since the work of Jenny (1941), it has been an axiom of soil science that topography is a factor influencing soil development. Not only do topographic factors directly influence pedogenetic processes (e.g., by their effects on particle stability (Brimhall et al., 1991)) or surface water distribution (Moore et al., 1993), but variations in landform may reflect underlying changes in parent material and differences in age of the soil profile. As most of the soil P is associated with particle surfaces, soil particle movement in form of surface erosion is likely to be an important mechanism for the redistribution of P within the landscape (Strohbach, 1985). Erosion is basically a natural occurring process on all land, depending on the erosive force of rain, soil erodibility, topography and soil cover (Morgan, 1999). However, it is well understood that human activities, in form of crop management and tilling practices, can accelerate erosion events.

To test the effect of geomorphology on the distribution of soil P primary (slope, profile curvature, plan curvature and elevation) and secondary attributes (wetness index, LS Factor) were calculated and entered as covariates in the GLM procedure.

Kassow

In Kassow, the site with very heterogeneous parent material, topography appeared to have very little effect on the variability of soil P. None of the primary terrain attributes was found to be correlated with $CaCl_2$-P, AAC-P or WH-P (Appendix, Tab. A.24-A.26). For AR-P a significant negative correlation was found with elevation ($p = 0.05$, Appendix, Tab. A.23), indicating that AR-P increased along the topographic gradient, with highest concentrations found in areas of low altitude. For the secondary terrain attributes, the wetness index was found to have no effect on the distribution of any of the P fractions, and the LS factor only on the distribution of $CaCl_2$-P. P in $CaCl_2$ decreased significantly ($p < 0.0001$) with an increasing LS factor.

Warberg

In contrast to Kassow the Warberg study site consisted of relatively uniform parent material (Chapter 3.3.2). A large proportion of the local soil variation should therefore be attributed to either management practices or topography. It is well understood that in Loess derived soils the most influential factor resulting in a variation of soil texture is surface erosion, whereby illuviated clay from the B horizon is brought to the soil surface (Peinemann and Brunotte, 1982).

With the exception of AR-P, which was found to be not correlated with any of the primary terrain attributes, the GLM procedure showed a very strong influence of terrain attributes on the variation in soil P fractions (Appendix, Tab. A.27-Tab. A.29). The distribution of $CaCl_2$-P was found to be influenced by slope ($p < 0.001$), elevation ($p < 0.001$) and profile curvature ($p < 0.01$); the distribution of AAC-P by slope ($p < 0.001$); and the distribution of WH-P by profile curvature ($p < 0.01$) and elevation ($p = 0.06$). Of the secondary attributes, the wetness index was found to have only a significant impact on AAC-P and $CaCl_2$-P, whereas the LS factor was found to be highly significantly correlated with all P fractions. However, the topographic analysis of individual fields, revealed that fields with the highest average P concentrations display the highest elevation, the steepest slopes and the largest LS factor (Tab. 3.7). Assuming that the differences in P concentrations are caused by fertilisation (Chapter 3.3.1), it was concluded that the result of the GLM did not reflect the redistribution of P as a consequence of topography, but rather of fertiliser placement.

Tab. 3.7: Mean and RSD values (%) for P concentrations (mg kg^{-1}), C_{tot} (%) and topographic parameters, slope (%), LS factor, elevation (m), for individual fields in Warberg.

	Individual fields in Warberg									
	BB		**M3**		**GB**		**M2**		**M1**	
	Mean	**RSD**	**Mean**	**RSD**	**Mean**	**RSD**	**Mean**	**RSD**	**Mean**	**RSD**
$CaCl_2$-P	1.16	64	0.81	58	0.56	83	0.94	48	0.38	100
AAC-P	117	32	114	29	108	34	100	33	77.4	45
WH-P	336	57	222	44	186	47	168	30	139	43
AR-P	572	34	538	24	478	26	431	23	377	24
slope	8.26	24	7.01	25	5.03	15	4.95	21	4.93	15
LS factor	3.46	45	2.76	58	2.15	26	2.18	39	2.12	32
elevation	166	3	164	4	166	4	158	4	150	3
C_{tot}	1.60	52	1.20	26	1.07	24	1.04	21	0.98	23

After filtering out the effect of P application by local standardisation (Chapter 2.6.4) the P fractions were only found to be significantly correlated to slope. All P fractions were found to decrease with increasing slope, indicating that the P concentrations was lowest on mid-slope positions. However, splitting the study site according to the direction of the two main slopes reveals, that for field BB and M3, which are effected by a steeper topographic gradient in the northsouth direction of the study site, z-scores of AR-P and WH-P increased with increasing slope (Fig. 3.18).

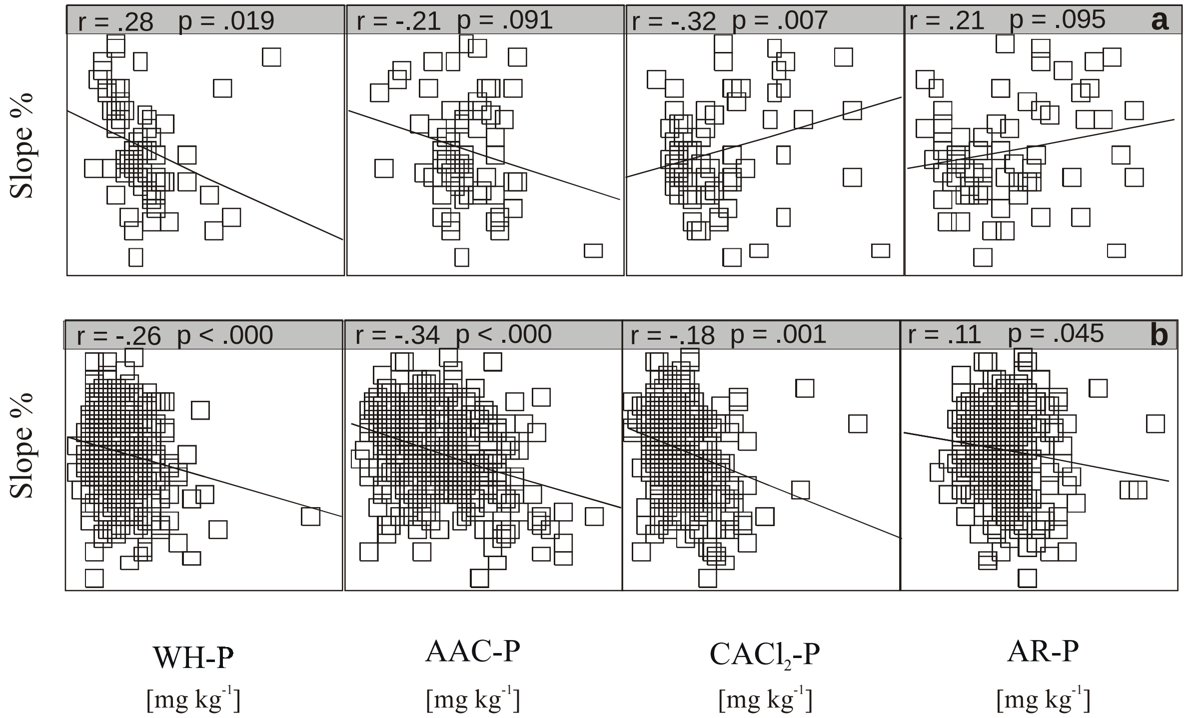

Fig. 3.18: Scatterplot and correlation coefficient for z-scores of soil P fractions and slope of fields BB, M3 (a) GB, M1, M2 (b) in Warberg.

Ceveiro

Besides having the most complex parent material, Ceveiro displayed also the most pronounced topographic relief. With the exception of elevation, none of the primary terrain attributes analysed showed an effect on the variation of soil P. The concentration of P in all four extracts was found to decrease significantly with decreasing altitude ($p < 0.001$). The LS factor was found to affect the distribution of AAC-P and Resin-P significantly, but not the distribution of WH-P and AR-P (Appendix, Tab. A.31-Tab. A.34).

Despite the general understanding that soil surface erosion is the main factor controlling the export of soil P from agricultural soils (Catt, et al., 1997) the GLM procedure revealed that the effect of geomorphology on the distribution of soil P pools in all three study sites was generally low. Of the primary terrain attributes only elevation was found to influence the distribution of soil P. Whereby, in Kassow only the sparingly available P pool and in Ceveiro all P fractions decreased with increasing elevation. The LS Factor re-distributed the readily available P pool in the sandy Cambisol (Kassow) and the reversibly available P pool in the soils of the Ceveiro study site. In Warberg, no clear relationships between the distribution of P pools and geomorphology could be derived.

3.4 Semi-variogram analysis of phosphorus species in Kassow, Warberg and Ceveiro

One of the key objectives of this work was to employ variography as a tool to model the spatial continuity of soil P fractions. It was emphasised that the spatial distribution of ancillary data (parent material, primary soil properties), that was found to have an effect on the distribution of the individual soil P fractions, was used as an decision aid for the modelling process (Chapter 2.6.2). Thus particular features of the experimental semi-variogram that could not be explained by the specific features of the study site were deemed spurious and were not modelled, whereas ancillary information lead to model features that were not apparent on the experimental curves.

3.4.1 Kassow

The fitted variogram models revealed that in the Cambisol in Kassow individual P fractions displayed different autocorrelation functions (Tab. 3.8). The P fractions did not only differ in their spatial ranges, but also in the strength and direction of their spatial distribution. The directional experimental variograms for AR-P (Appendix, Fig. A.4 & A.5) and WH-P (Appendix, Fig. A.6 & A.7), both displaying similar distribution pattern, exhibited different ranges for different directions. The degree of this geometric anisotropy was measured by the anisotropy ratio, which is equal to the range of the minor axis divided by the range of the major axis. The more dissimilar the ratio is from one, the stronger the geometric anisotropy. The calculated ratio for AR-P and WH-P was only 0.53. The major axis coincided with the topographic gradient of the field, which is also the direction of tilling operations (135°). $CaCl_2$-P was found to be non stationary, displayed a strong trend for the northeast direction (45°) of the field, which is perpendicular to the direction of tilling operation. After detrending the variogram of the residuals was found to be omnidirectional (Appendix, Fig. A.9) No preferential direction was found for the distribution of AAC-P (Appendix, Fig. A.8).

Tab. 3.8: Parameters for the spherical semi-variogram models for P species in the Cambisol at Kassow (E12° 06', N53° 10').

	Direction	Nugget (C_0)	(C_1)	Sill (C)	NR	Range a (m)
AR-P	135°	0.32	0.59	0.91	35	209
AR-P	45°	0.32	0.69	1.01	32	112
WH-P	135°	0.29	0.61	0.90	32	208
WH-P	45°	0.29	0.66	0.95	31	111
AAC	omni	0.65	0.39	1.04	63	253
$CaCl_2$	omni	0.60	0.40	1.00	60	108

The observed differences in ranges were relatively large with the autocorrelation of AAC being approximately 50 m longer than the main axis of AR-P and WH-P and about 150 m longer than the distribution of the detrended $CaCl_2$-P. This pronounced spatial continuity was not mirrored by the distribution of any of the soil texture classes (Tab. 3.9). However, the range of the minor axis of the AR-P and WH-P as well as the range of the $CaCl_2$-P distribution coincided with the ranges obtained for medium loamy sand (Sl3), loamy sand (lS) and high loamy sand (SL3) (see also Appendix, Fig. A.10-Fig. A.13).

Tab. 3.9: Parameters for the spherical standardised, indicator semi-variogram models for soil texture classes of the Cambisol at Kassow (E12° 06', N53° 10').

	Direction	Nugget (C_0)	(C_1)	Sill (C)	NR	Range a (m)
lS	omni	0.48	0.47	0.95	51	113
Sl3	omni	0.36	0.62	0.98	37	100
SL3	omni	0.23	0.70	0.93	25	110
sL	omni	0.15	0.86	1.01	15	174

The large NR of the variogram models for AAC-P and $CACl_2$-P indicate that more than 50 % of their spatial variation was not explained by the models. This indicates that a significant proportion of the within-field variation of AAC-P and $CaCl_2$-P was below the scale of sampling. For AR-P and WH-P the nugget variance appeared to be larger for the direction of maximum continuity (135°), than for the minor axis of the distribution (45°)(Appendix, Fig. A.4-A.7). However, it was assumed that the nugget variance was isotropic distributed and thus modelled accordingly. For both P fractions the derived models showed a good fit, explaining about 70 % of the observed variation. According to Cambardella et al. (1994) the spatial dependency of the P fractions can be evaluated as moderate (Chapter 2.6.2).

3.4.2 Warberg

In order to investigate the distribution of different soil P species throughout the entire sub-catchment it was necessary to filter out the effect of individual fields. This was done by standardising the data locally (Chapter 2.6.3.). All P species displayed geometrical anisotropy, with the major and minor axis being the northsouth (90°) and eastwest direction (0°) of the sub-catchment (Appendix, Fig. A.14-A.21). For the major axis a nested model consisting of two spherical model and a nugget effect was fitted. A comparison of the ranges reveals two different spatial scales: a shorter omnidirectional between 89 and 109 m (Tab. 3.10) and a longer (> 200 m) one, only apparent for the major axis.

With the exception of AAC-P, calculated NR values did not correspond to calculated RSD values. This indicates a polarisation of extreme values in one area of the study site and thus reflects the strong geometrical anisotropy. The largest NR value was calculated for AR-P (RSD = 29 %), whereas small ratios were obtained for WH-P (RSD = 55 %) and $CaCl_2$-P (RSD = 71 %). Only for AAC-P similar values for RSD (36 %) and NR were calculated. According to Cambardella et al. (1994) the spatial dependency of AR-P, AAC-P and $CaCl_2$-P can be evaluated as moderate, for WH-P as strong (Chapter 2.6.2).

Tab. 3.10: Parameters for the spherical semi-variogram models for local standardised soil P species in the Luvisol at Warberg.

	Direction	Nugget (C_0)	(C_1)	Sill (C)	NR	Range a (m)
AR	omni	0.56	0.33	0.89	63	109
WH	omni	0.20	0.70	0.90	22	104
AAC	omni	0.26	0.67	0.93	28	105
$CaCl_2$	omni	0.35	0.60	0.95	37	96

3.4.3 Ceveiro

The very high variability within the data set resulted in very “noisy” experimental semi-variograms (Appendix, Fig A.22-A.27) Furthermore, the sparse sampling point distribution along the northwest axis, which coincided with the direction of the main topographic gradient of the study site did not allow for an exact modelling of the directional variograms. Nevertheless, the variogram-surface visualises the geometrical anisotropy displayed by AR-P and Resin-P (Fig. 3.19a and b). The variogram surface is a two-dimensional plot of the experimental semi-variogram values in the system of coordinates (h_x, h_y). The centre of the map corresponds to the origin of the semi-variogram $\gamma(0) = 0$. Semivariogram values are small near the origin (0,0) and increase with the distance from the origin. When the variation is isotropic, the increase is fairly similar in every direction; hence the map shows concentric contour lines. Conversely, geometric anisotropy appears as elliptical contour lines whose major axis indicate the direction of maximum continuity (Goovaerts, 1997). From the variogramsurfaces (Fig. 3.19) it is evident that AR-P and Resin-P displayed a longer spatial continuity for the northwest (143°), the direction of the main topographic gradient. The minor axis coincided with the direction of the river (53°).

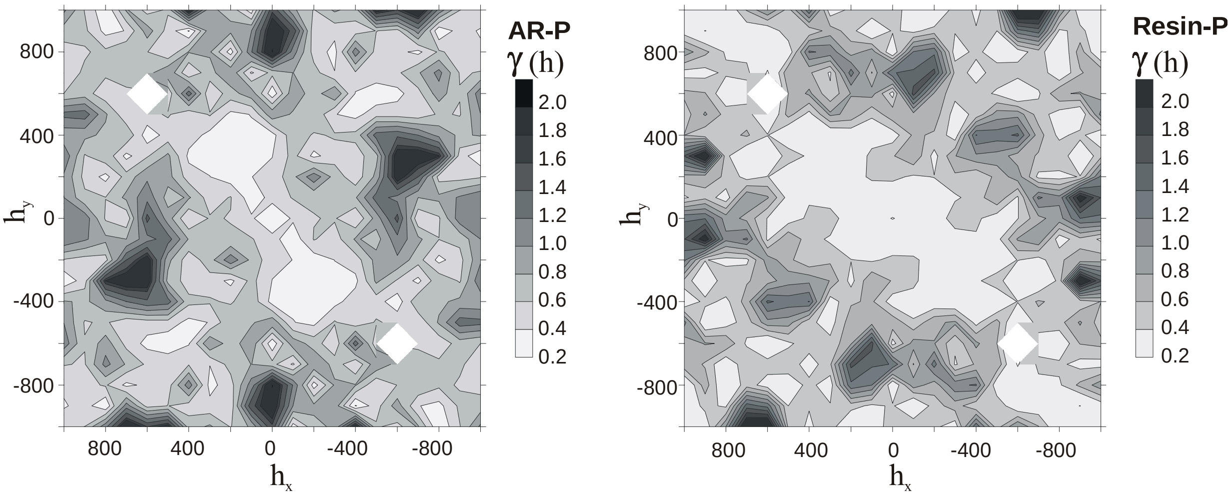

Fig. 3.19: Variogramsurface of normal score transformed P concentrations in AR and Resin for the Ceveiro study site, showing geometric anisotropy.

No preferential direction was found for the distribution of AAC-P and WH-P (Tab. 3.11). As outlined above due to the large spacing of the sampling points and the high variability of the P concentrations, no satisfying model could be fitted through the semi-variogram of AR-P and Resin-P for 143º. The range for this direction was estimated therefore from the omnidirectional semi-variograms for these P fractions (Appendix, Fig. A.23 & Fig. A.25).

Tab. 3.11: Parameters for spherical semi-variogram models for normalised soil P species for the Ceveiro study site.

	Direction	**Nugget (C_0)**	**(C_1)**	**Sill (C)**	**NR**	**Range a (m)**
AR-P	53˚	0.29	0.47	0.76	38	280
AR-P	143˚	0.29	0.46	0.75	39	808
WH-P	omni	0.32	0.38	0.7	46	57
AAC	omni	0.32	0.48	1.00	52	70
Resin	53˚	0.27	0.27	0.54	50	296
Resin	143˚	0.2	0.59	0.81	25	744

Although for major soil types, land-uses and geological formations well behaved indicator variograms could be modelled, the distribution pattern did not coincide with any of the P fractions (Tab. 3.12, Appendix, Fig. A.28-A.35). However, the minor axis of the distribution of Resin-P and AR-P were found to correspond to the distribution of clay (Chapter 2.1.6, Tab. 2.6).

Tab. 3.12: Model parameters for standardised indicator variograms for land-use, soil type, geological formations in the Ceveiro study site.

	Direction	**Nugget (C_0)**	**(C_1)**	**Sill (C)**	**NR**	**Range a (m)**
sugar cane	omni	0.40	0.62	1.02	39	328
pasture	omni	0.05	0.94	0.99	5	456
forest	omni	0.70	0.34	1.04	67	398
Corumbataí	omni	0.10	0.95	1.05	10	510
Pirambóia	omni	0.24	0.70	0.94	26	500
Serra Geral	omni	0.23	0.80	1.03	22	170
Paleudult	omni	0.03	0.59	0.62	5	480
Udorthent	omni	0.04	0.50	0.54	7	430

The geostatistical analysis revealed that all investigated P fractions, representative of functional P pools, displayed spatial autocorrelation, which was quantitatively analysed using variography. In Kassow, functional P pools did not only differ with respect to their spatial ranges, but also in their distribution pattern and strength of the autocorrelation. The ranges of P fractions decreased in the order: AAC-P > AR-P/WH-P (1. structure) > AR-P/WH-P (2. structure) > $CaCl_2$. In Warberg functional P pools were not found to differ significantly in their spatial ranges (~100 m), but in the strength of their autocorrelation. In Ceveiro, the functional P pools were found to differ significantly, with the reversibly available P pool displaying the shortest range (57–70 m) and the sparingly available P pool the longest (280 m, 1. structure; 808 m, 2. structure).

4. Discussion

The main objective of this research work was to investigate factors responsible for the spatial variability of P species. To achieve this goal four areas of investigation were conducted: the selection of P extraction methods that extract soil P fractions which are representative of functional P pools; the quantitative assessment of the spatial distribution of these functional P pools using geostatistical methods, a comparison of the spatial continuity of these functional P pools, as well as explaining the predominant environmental mechanisms which gave rise to the observed patterns and finally, to investigate the feasibility of geostatistical methods to asses the suitability of different extraction methods for plant available P.

The discussion of the results of this thesis starts, therefore, with a discussion of the extraction methods used with respect to their association with function soil P pools (Chapter 4.1). Based on these discreet P pools the chemical speciation of soil P within the main soil types is discussed (Chapter 4.2). The evaluation of the spatial variation of soil P pools (Chapter 4.3) starts with an assessment of the conditions which result in the spatial speciation of P, the chemical speciation with site specific environmental factors and the subsequent formation of geochemical species that display different spatial dependencies. The chapter is completed with a discussion of the main environmental factors that control the spatial continuity of individual pools. As geostatistical methods have never been used to investigate speciation processes their suitability to do so, based on the results of this work are evaluated (Chapter 4.4).

Apart from increasing the knowledge of P dynamics in the environment, the rationale of this work was derived from the implementation of SSNM via Precision Agriculture and balanced P fertilisation regimes. Thus, geostatistical methods are further evaluated for the assessment of soil analysis methods (Chapter 4.5).

4.1 Evaluation of extraction methods used for P extraction

Despite the development of a wide range of soil test methods (Kamprath and Watson, 1980; Fixen and Grove, 1990; McColum, 1991), fractionation procedures (Chang and Jackson 1957; Kurmies, 1972; Syers et al., 1972) and mechanistic approaches (Barrow, 1980; McLaughlin et al., 1981; Lookman, 1995; Agbenin and van Raij, 2001), reliable estimates of phytoavailable soil P have seldom been achieved due to the complexity of soil P speciation.

Considering that, as far as mineral sources are concerned, only free orthophosphate is available to plants an alternative approach is to use the solubility of a P species as an indication of its phytoavailability (Hedley, 1982). The underlying assumption is that extractants of varying extraction force (Williams, 1966) dissolve P fractions of different plant availability. Mild extractants will remove rapidly available P from the soil and stronger ones stable or occluded P forms (Hedley et al., 1982).

The Hedley procedure, which involves a seven step sequential extraction, has been used to elucidate the differences in sizes of P fractions in soils receiving various treatments (Richards et al., 1995; Schmidt et al., 1996; Leinweber, 1996), with differing weathering intensity (Beck and Sanchez, 1994; Cross and Schlesinger, 1995), and under various cultural practices (Lawrence and Schlesinger, 2001; Zheng et al., 2001; Zheng et al., 2002).

Although these studies are important contributions to the understanding of the biogeochemical cycling of P, Guo and Yost (1998) suggested that grouping the soil P continuum into fewer functional pools could be of greater practical value with respect to management purposes.

A simplified scheme for grouping soil P into two dynamic pools, a labile (or available) pool and a stable (unavailable pool) has been used for modelling long-term crop response to fertiliser P (Wolf et al., 1987) and for evaluating residual available P (Russell, 1977). However, it has been proven that “absolutely” plant-unavailable P, so called “occluded” P, does not exist during long-term P transformations, although some P fractions in the soil P continuum at least appear irreversible on a short time scale.

Jungk et al. (1993) demonstrated this for a Luvisol from Loess in Lower Saxony. During a 15 year field trial a substantial proportion of the plant P demand was satisfied by soil P reserves. This so called “residual fertiliser effect” has also been demonstrated for many Brazilian soils (Ball-Coelho et al. 1993; Warren, 1994; Agbenin, 1995).

Guo and Yost (1998) proposed, therefore, to partition the total soil P reserve into three discreet functional pools: readily available, reversibly available, and sparingly available. The readily available P pool represents P in solution that is readily accessible by plant roots. The reversibly available P denotes the soil P reserve that can be converted into soluble (readily available) P, by either living organisms or weathering during the growth season. Whereas the sparingly available P is not available on a short time scale such as one or more crop cycles, but a small fraction of this pool may become available during long-term soil transformation (Guo and Yost 1998).

For the purpose of this research work it was, therefore, decided to select P extraction methods that represent the P pools, as suggested by Guo and Yost (1998).

The P concentration in the soil solution is generally estimated using water or a dilute electrolyte. Scientist differ as to which of the two extractants gives the best estimation of the readily available P pool. Water will suspend both, colloidal bound and molecular P forms, but the presence of colloidal particles will result in an overestimation of soluble P (Haygarth et al., 1997; Sinaj et al., 1998; Hens, 1999). This was confirmed by the results of this work as H_2O was found to extract more P from reference material than $CaCl_2$ (Chapter 2.4, Tab. 2.13).

Some scientist argue that suspending the soil with $CaCl_2$ will alter the isoelectric point of soil colloids and may result in a precipitation of Ca-phosphate and therefore in an underestimation of soluble P (White and Beckett, 1964, Hylander et al., 1996). However, as in all four soil types Ca^{2+} was found to be the dominant ion (Chapter 2.1.2, Tab. 2.3), it was assumed that re-precipitation of Ca-P is negligible. Furthermore, the extraction force of H_2O was not found to be statistically different when compared to standard methods estimating the reversibly available P pool (Chapter 2.4.2, Tab. 2.13). For the purpose of partitioning the soil P continuum into discreet pools, preference was, therefore, given to the $CaCl_2$ method.

To estimate the total soil P pool the AR method was selected based on an operational point of view as for a large amount of samples acid digestion is the most economic one. When compared to the so called “true total analysis” (WEPAL, 2000) the AR method extracted on average 80 % of the “true total P concentration” (Chapter 2.4.1, Tab. 2.10). For the purpose of this work the inference was drawn that the AR method provided a suitable estimation of the total P in soil.

The sparingly available P pool, is that part of the total soil P reserve that is neither readily nor reversibly available (Guo and Yost, 1998). Comparing the proportion of the readily and the reversibly available P fraction of the total soil P for the reference material for each study site revealed that between 81 % and 96 % of the total soil P pool was sparingly available (Fig.

4.1). It was, therefore concluded that the total soil P concentration as estimated by the AR method was a suitable indicator of the sparingly available P pool.

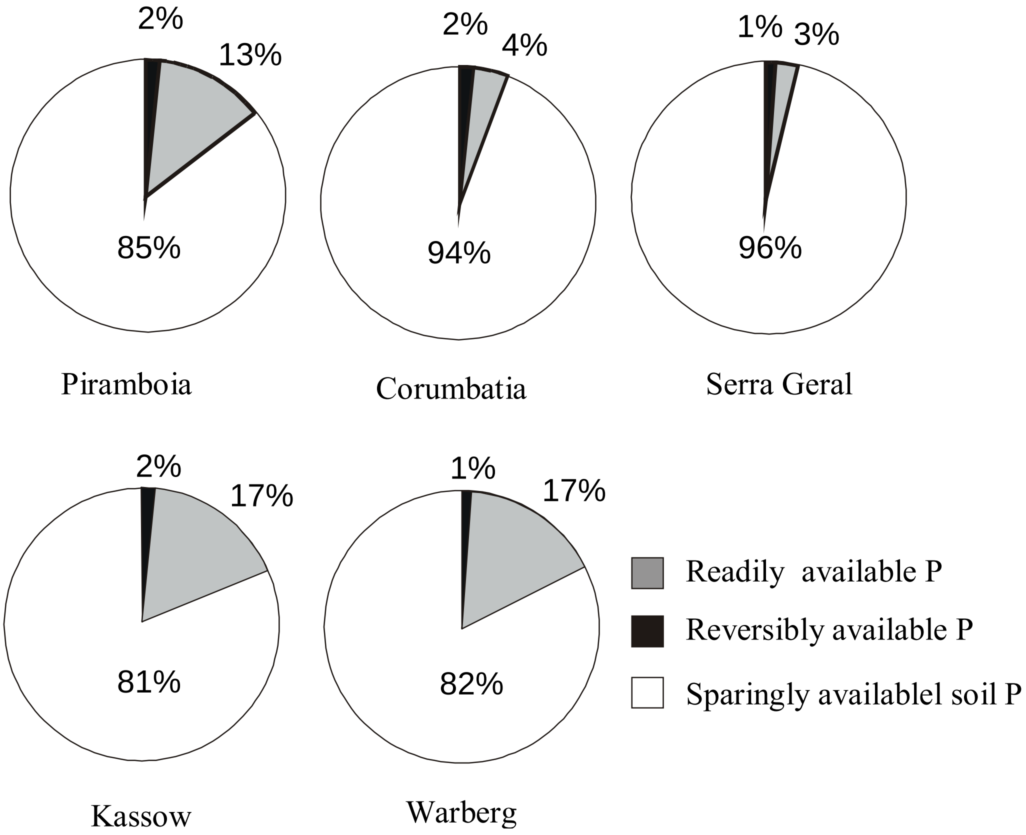

Fig. 4.1: Percentage of readily and reversibly available P fractions on the total soil P concentration in reference material from Ceveiro, Kassow and Warberg. Readily available P was calculated as the average of P extracted by $CaCl_2$ and H_2O, whereas reversibly available P was calculated as the average of P extracted by Olsen, AAC, CAL, WH and Bray1 (Chapter 2.4.2, Tab. 2.12).

Standard extraction methods that place soils in the order of crop responsiveness to P and thus estimate the reversibly plant available P pool differ, from country to country. Despite the widespread use of chemical extraction procedures, the chemical reactions by which available P is obtained are not well understood (Curtin et al., 1987). There is neither a clear assignment of standard P tests to individual P fractions nor is there a general agreement as to which method gives the best estimate of reversibly plant available P pool as the relative performance of each method varies for different soils (Sharpley, 1991; Leal et al., 1994). On that account it was decided to test a variety of methods commonly used and select the one that showed a significant difference to the methods estimating the readily plant available P and the total P pool.

Out of the four standard soil P test only AAC-P and Bray I-P were found to differ significantly with respect their extraction force from $CaCl_2$-P and AR-P, for all reference materials analysed (Chapter 2.4.2, Tab. 2.13). Bray I has already been found to overestimate labile P in tropical soils containing apatite (Leal et al., 1994). In addition, the method is known to underestimate labile P in soils with a pH larger than 6.8 (Knudsen and Beegle, 1988). This could explain the relative low Bray I-P concentration for the Warberg reference material (Chapter 2.4, Tab. 2.12). For the selection of a suitable method for representing the readily plant available P fraction, preference was, therefore, given to the AAC method.

The WH-method is a standard method to determine plant-available Cu and Zn (Westerhoff, 1954/1955). In the literature no information was found that associated the WH method with a specific soil P pool. However, based on its acidic strength it is comparable to 1M HCl, which is commonly used in sequential P extraction procedures (Hedley et al., 1982). As the nitrate and chloride ions have very little effect on the extraction (Nelson et al., 1953) their extraction force is mainly a function of their pH. Acidic extractions of this strength have been shown to remove mainly apatite-type minerals (Williams et al., 1971), but are also assumed to extract occluded P in more weathered soils (Williams et al., 1980). However, they are not known to oxidise to any large extent the organic P fraction (see also Saunders and Williams, 1995).

It is well known that the performance of dilute acid extractions is influenced by the pH of the soil. Dilute acid extractions tend to underestimate the labile P concentration especially in soils with a high content of carbonates (Werner and Wiechman, 1972; Kamprath and Watson, 1980).

For the calcareous Luvisol from Warberg AAC was found to extract less P than WH for samples with a high carbonate and total P content (Chapter 3.2.2, Fig. 3.7). The conditional plot, which shows AAC-P as a function of WH-P for groups of soil samples that vary with respect to their $CaCO_3$ content shows, that samples with a $CaCO_3$ content larger than 0.8 % and a WH-P concentration of approximately 200 mg kg^{-1} deviate from the linear regression line between AAC-P and WH-P (Fig. 4.2).

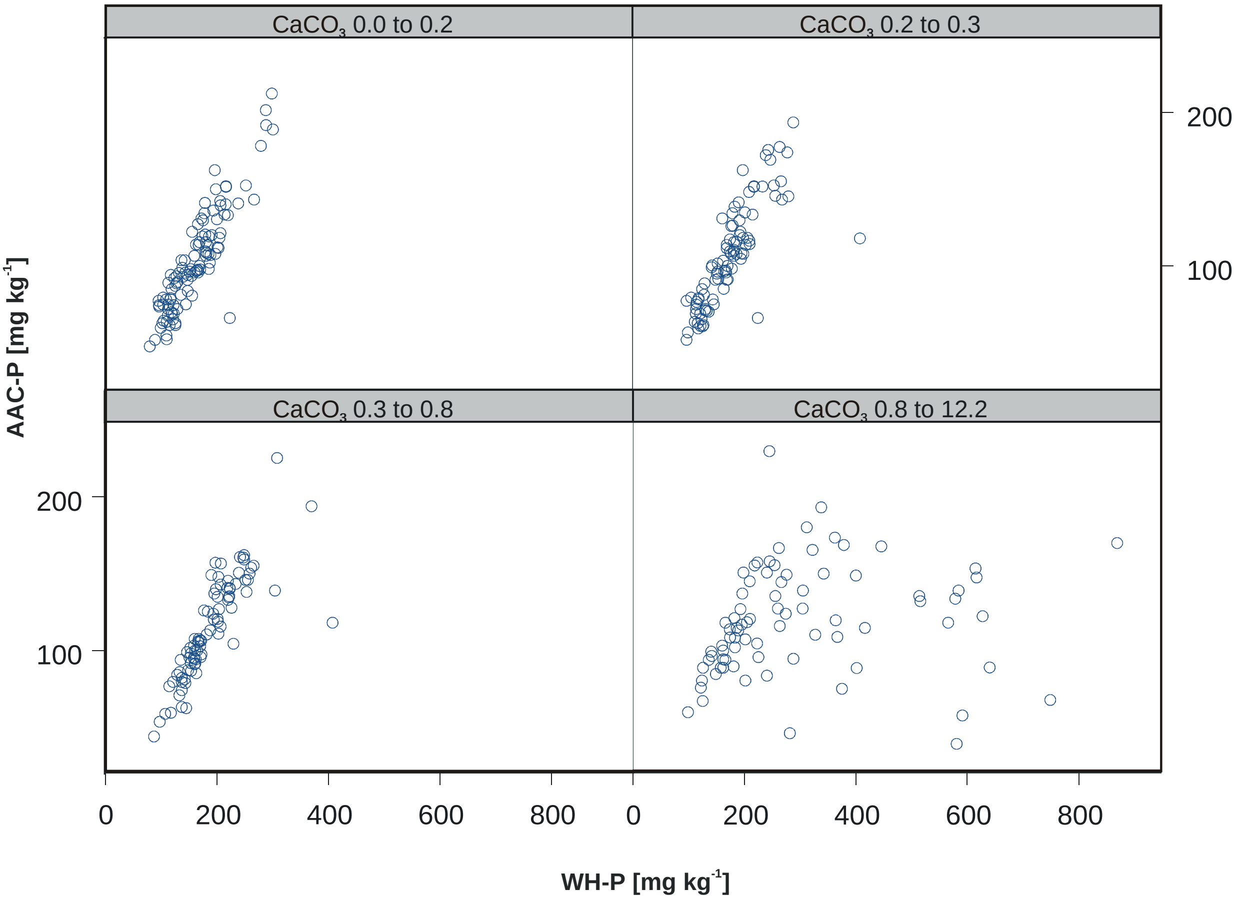

Fig. 4.2: Conditional plot of AAC-P vs. WH-P for the Luvisol from Warberg, whereby the conditional variable is the $CaCO_3$ [%] content of the samples. Intervals were chosen to present even number of counts.

This phenomenon could be due to

- a re-precipitation of soluble P with Ca^{2+} or $CaCO_3$ (Danen-Lowerse et al., 1994) or
- a neutralisation of the acid and a subsequent decrease in extraction force.

In contemplation of investigating the cause of this phenomenon the ACC extracts from field BB in Warberg, which showed the lowest correlation between AAC-P and WH-P (Fig. 4.2) were analysed, in addition to the standard colourimetric method, with an inductive coupled plasma optical emission spectroscope (ICP-OES). The concentration of AAC-P analysed by ICP-OES was found to be on average 13 % higher than colourimetrically determined AAC-P. Nevertheless, a comparison of the two analytical procedures resulted in a significant correlation between the methods, whereby P measured by ICP-OES accounted for 98 % of the colourimetrically determined P (Fig. 4.3).

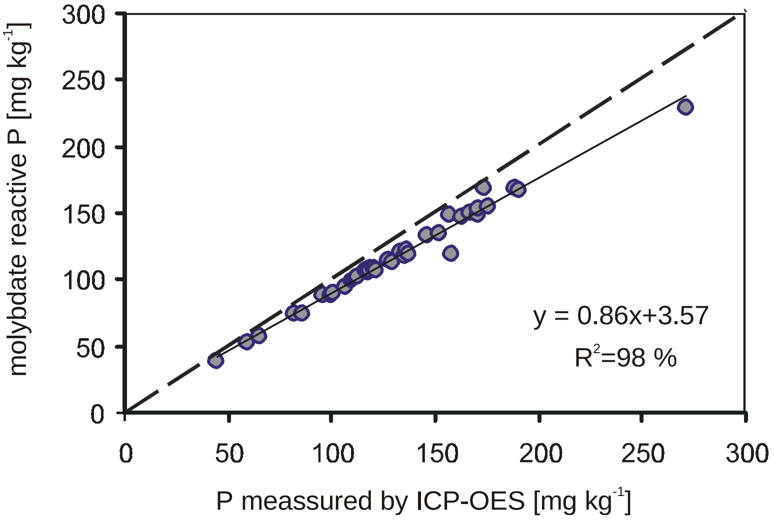

Fig. 4.3: Scatterplot of molybdate reactive P (colourimetrical) and total P (ICP-OES) in AAC extracts of a Luvisol.

The colourimetric analysis of P will only determine molybdate reactive P (MRP), which consists predominantly of free ortho-phosphate in solution (Clescere et al., 1985). In contrast, analysing the AAC extract by ICP-OES, the total P concentration, soluble or particulated, will be obtained (Zbíral, 2000). Thus, the higher P concentration obtained by ICP-OES indicates that about 13 % of the soil P extracted by AAC was not free in solution, but bound to soil colloids.

The linear correlation of AAC-P obtained by both analytical methods implied that the total P concentration in the AAC extract was decreased for soil samples with a $CaCO_3$ greater than 0.8 when compared to the WH-P concentration. A re-precipitation of Ca-P would have resulted in a decrease of MRP, whereas the total P concentration would have stayed the same.

Thus, it was concluded that re-precipitation of Ca-P did not occur in the AAC extract, but that the acidic strength of the AAC method was reduced in soils with a high carbonate content. This conclusion was further supported by the finding, that with increasing $CaCO_3$ content in the soil the pH of the AAC-extract increased (Fig. 4.4).

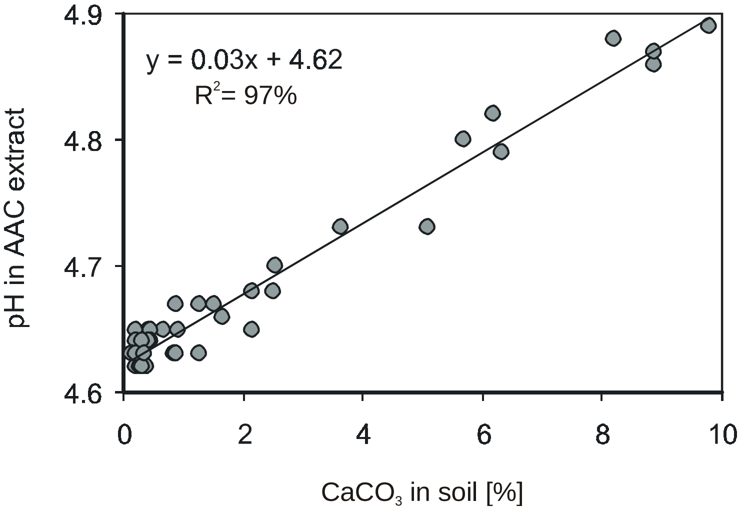

Fig. 4.4: Scatterplot of the pH in AAC extract vs. $CaCO_3$ content for soil samples from field BB in Warberg.

Zbíral (2000b) arrived at the same conclusion, demonstrating that the extraction of P by acid extractants was strongly dependent on an increase of pH during extraction.

4.2 Evaluation of the chemical speciation of soil P in Kassow, Warberg and Ceveiro

In the two temperate soils all four extracts were found to differ significantly with respect to their extraction force and thus, it was suggested, that these methods extract P fractions, that each are representative of a functional P pool (Chapter 3.2.1). However, in both soils, Kassow and Warberg, the concentrations of WH-P and AR-P were found to be highly correlated, indicating that both P fractions are in equilibrium with each other (Chapter 3.2.2). On the other hand, the relatively low correlation between WH-P and AR-P for non calcareous soils in Warberg indicated, that the differences in P concentrations could not be solely attributed to the different acidic strength of the extractions (Chapter 3.2.3, Fig. 3.7). It is suggested, that the difference was predominantly caused by the lack of oxidising force of the WH extract and subsequently to presence of organic P (Chapter 4.1.1). The difference in extraction force between the two methods was about 60 %, which corresponds well with the amount of organic P (29 to 65 %) usually reported for agricultural soils (Harrison, 1987).

In the light of the above discussion it was, therefore, concluded that P extracted by WH can not be associated with a specific functional soil P pool, but is indicative of the sparingly available P pool.

The chemical approach to evaluate the P status of a soil considers the factors: intensity, quantity and capacity. The "intensity factor" is a measure of the gradient in the electrochemical potential of the phosphate ions across the adsorbing surfaces of plant roots and in its simplest form can be regarded as the P concentration in the soil solution (Olsen and Khasawneh, 1980). Integrated over time the intensity factor is the true quantity of the bioavailable P (Fox and Kamprath, 1990).

The quantity, or so-called "richness factor" (Williams, 1966) describes the amount of P that can potentially become available during the growth season (Olsen and Khasawneh, 1980). It is referred to as the reversibly available P pool (Guo and Yost, 1998), and thus represented by AAC-P in the temperate soils from Kassow and Warberg and by AAC-P, WH-P and Resin-P in the tropical soils from Ceveiro (Chapter 3.2.1).

The ratio between the intensity and the quantity factor, reflecting the ease of P withdrawal by the plant, is expressed as the "capacity factor" (Williams, 1966). The capacity factor, which is an indication of the P adsorption capacity of the soil, is predominantly dependent on the negative surface charges, as well as the specific surface area of soil particles and is mainly a function of the weathering stage of a soil (Schwertmann and Taylor, 1989). As climatic conditions are the main factor controlling the weathering rates of soils, tropical soils usually display a higher anion adsorption capacity than temperate soils (McBride, 1994). As soils weather with the concurrence of decreasing pH, formation of secondary Fe- and Al-P minerals are favoured as their solubility decreases which results in decreasing pools of the readily available and the reversibly available P (Smeck, 1985).

According to the LK Hannover (1993) fertiliser recommendation which employed the CAL-Method (Schüller, 1969) the P status of the Cambisol (Kassow) was found to be below, whereas for the Luvisol (Warberg) it was well above the optimum range (Chapter 2.1.2). In addition, the median AAC extractable P concentration in the Cambisol was found to be approximately half of the median concentration in the Luvisol. The quantity, the intensity and the capacity factor are interdependent and influenced by the relative saturation of the total numbers of adsorption sites (Fixen and Grove, 1990). As such a large quantity factor, represented by reversibly available P can indicate either a low adsorption capacity of the soil or an oversupply, by either fertilisation or dissolution of primary minerals (Uehara and Gillman, 1981).

Considering that apatite has never been documented in temperate soils (Lookman et al., 1995) and Fe-phosphates only occur in buried alluvium and in peat under reducing conditions (Lindsay, et al., 1989) it was assumed that in Kassow and Warberg, geogenic primary phosphates do not exist. Considering that P input by atmospheric precipitation is relatively low (0.2-2 kg ha^{-1} y^{-1} (Scheffer and Schachtschabel, 1992)), total P concentrations are therefore directly dependent on P inputs by mineral fertilisers and manure. Thus, the relatively high total P concentrations for Kassow and Warberg, 1422 kg P $ha^{-1}$and 1325 kg P ha^{-1} respectively, indicate a continuous accumulation of P fertilised but not removed by plants (Chapter 3.1, Tab. 3.5). It is, therefore, suggested that the lower concentration of reversibly available P in Kassow is caused by the formation of less soluble phosphate minerals.

This assumption is supported by research investigating the reaction products of fertiliser P in calcareous and acidic, sandy soils. Richter and Matzel (1976) investigated the fate of P fertiliser in sandy, low pH soils, which were collected within the vicinity of Kassow, as well as in loamy Loess derived soils. They found that in all soil types the first reaction product was Brushit, but prolonged contact of fertiliser phosphate solution with the soil only led to the formation of Taranakites in the sandy soil. In addition, for soils with a pH larger than 6.3, they could prove the formation of octocalcium phosphate.

These findings are well in accordance with the general understanding that in calcareous soils the labile P fraction is replenished by Ca-phosphates, but in acidic soils by Al-phosphates (Werner, 1969; Werner and Wiechmann, 1972). It is proposed therefore that the observed differences in labile P between the Cambisol and the Luvisol are due to the lower solubility of Taranakites (Tab. 4.1).

Tab 4.1: Solubility products of some soil P fertiliser reaction products, adopted from Sample et al. (1980).

Mineral name	Compound	pKsp	Reference
Variscite	$AlPO_4 \cdot 2H_2O$	21.5-22.5	Taylor and Gurney (1964)
Taranakite	$Al_5K_3H_6(PO_4)_8 \cdot 18H_2O$	178.7	Taylor and Gurney (1961)
Brushite	$CaHPO_4 \cdot 2H_2O$	6.56	Moreno et al. (1960a)
Octocalcium phosphate	$Ca_8H_2(PO_4)_6 \cdot 5H_2O$	93.81	Moreno et al. (1960b)
Hydroxyapatite	$Ca_{10}(PO_4)_6(OH)_2$	111.82	Farr (1950)
Strengite	$FePO_4 \cdot 2H_2O$	35.35	Huffman and Taylor (1963)
Vivianite	$Fe_3(PO_4)_2 \cdot 8H_2O$	36.00	Gassner (1999)

pKsp = log Ksp, whereby Ksp is the solubility product constant, which is equal to the ionic product of the concentrations at equilibrium.

Within the Cambisol at Kassow the concentration of the readily available P pool was found to be much higher than in the Luvisol in Warberg. In both soils this pool was found to be negatively correlated with the clay content of the soil (Chapter 3.2.3, Fig. 3.10 & Fig. 3.11). As the clay content in general can be assumed to indicate the adsorption capacity of a soil (McBride, 1994), it is proposed that the lower $CaCl_2$-P concentration obtained from the Luvisol was caused by the higher adsorption capacity and hence, by the lower extraction force of the $CaCl_2$-P method in this soils.

For the two tropical soils it was shown that AAC, Resin and WH extracted P from the same functional pool (Chapter 3.2.1). Thus, only two functional soil P pools: the reversibly and the sparingly available P pool could be investigated with the extraction methods used.

The lack of any reliable data for the readily available P pool and the low extraction force of Resin, WH and AAC reflected the low P status and the very high P adsorption capacity of the soils in question. As a legacy of pedogenesis the total P status of tropical soil is a function of its weathering stage (Walker and Syers, 1976; Tiessen et al., 1984). The higher degree of weathering in the two tropical soils from Ceveiro in comparison to the two temperate soils from Kassow and Warberg is indicated by the decrease in base saturation (Chapter 2.1.2, Tab. 2.3), as well as an increase in Al saturation and soil acidity (Chapter 2.1.2, Tab. 2.3). In highly weathered soils the dominant minerals are kaolinitic 1:1 layer minerals, allophanic minerals and Al and Fe oxides. In contrast to the 2:1 layer minerals, predominant in temperate soils, these soil particles display a pH dependent charge, which favours anion adsorption under low acidic soil conditions (McBride, 1994).

With respect to the average concentration of the sparingly available P pool the two soils were found to be very different, with the Udorthent having a 70 % higher concentration. This difference is within the range reported for unfertilised tropical soils, with an average total P concentration of 680 mg kg^{-1} in Entisols and between 200 and 430 mg kg^{-1} in Utisols and Oxisols (Cross and Schlesinger, 1995).

A comparison of the frequency distribution of the two soil types for different land-uses reveals that most of the Paleudult (85%) was under sugar cane product, whereas more than 50 % of the Udorthent occurred under unfertilised systems (Chapter 2.1.1, Fig. 2.13). Considering, that the Ceveiro study site had been cultivated for at least 20 years (Bacchi et al., 2000) the total P concentration in soils under sugar cane was expected to be higher than under unfertilised soils.

However, Beck and Sanchez (1994) reported an increase in total P concentration of a uncultivated Paleudult from approximately 20 to 80 mg kg^{-1} after 18 years of cultivation. It was concluded therefore that 20 years of fertiliser application was not efficient enough to alter the primary properties of the soils with respect to their P status. This is further supported by the findings that under sugar cane the sparingly available P pool was found to be the lowest (Chapter 3.3.1, Fig. 3.14), indicating that rather than increasing the P status of the soil under intensive agricultural production, the soils are mined of their P reserves.

For the reversibly available P pool it was suggested that, the overall poor correlation between AAC-P, WH-P and Resin-P indicated a large degree of chemical speciation within this pool (Chapter 3.2.2). The very large variation of the P fractions is thought to reflect the variability of the sugar cane plantations with respect to management and age of the cane (Chapter 2.1.3). As P was applied only once during the seeding of the cane, older plantations were expected to have a lower soil P concentration than younger ones. This was supported by the presence of fertiliser granules in some of the soil samples (Chapter 3.2.3).

Additionally, as both mulch and burning management systems were practised on the sugar cane plantations, a high variation with respect to soil nutrient status had to be expected (Ball-Coelho et al., 1993).

4.3 Evaluation of the spatial variation of functional P pools in the study sites

The partitioning of the soil P reserve between functional pools depends, on the one hand, on soil parent material and pedogenesis (Beauchemin and Simard, 2000) and, on the other, on the selective depletion or refill of a particular soil P pool, by either plant uptake, physical movement, or P input, for instance by fertiliser.

For a German Luvisol, Strohbach (1986) demonstrated that the relation between the sparingly available and the reversibly available P pool is dependent on the specific adsorption capacity of the soil for P. He concluded that an estimation of the reversible P pool, therefore, could not be used to estimate the P status of a field. In a comprehensive investigation of soil types in the former GDR, Jentsch (1986) arrived at a similar conclusion. He found that the correlation between the two pools increased with decreasing percentage of clay sized particles in the soil.

In the present research work, for all investigated soil types, a partitioning of the functional P pools with respect to their correlation with other soil parameters was shown (Chapter 3.2.3 Fig. 3.10–Fig. 3.12). The results correspond to Jentsch's (1986) findings: there was no partitioning between the reversibly available and the sparingly available P pool for the sandy soil in Kassow, whereas for the loamy soils from Warberg and Ceveiro a strong partitioning between these two pools occurred. Additionally, in Kassow and Warberg the readily available P pool was found to be negatively correlated with the clay content of the soil (Chapter 3.2.3, Fig. 3.10 & Fig. 3.11).

In contrast, the observed spatial division of the functional P pools is not simply explainable by the adsorption characteristics of individual soils. Although a strong spatial speciation of soil P with respect to the sparingly available and the reversibly available P pool was found for the two tropical soils in Ceveiro (Chapter 3.4.3), very little spatial speciation was observed in Warberg (Chapter 3.4.2). In contrast, in the sandy Luvisol (Kassow) the functional P pools did not only differ in their spatial ranges, but also in the strength and direction of their spatial distribution (Chapter 3.4.1).

In the previous chapter (Chapter 4.1) it was outlined that the quantity (reversibly available P pool), the intensity (readily available P pool) and the capacity factor (adsorption capacity of the soil) are interdependent and influenced by the relative saturation of the total numbers of adsorption sites (Fixen and Grove, 1990). In P-saturated soils the impact of the capacity factor to control the P status of a soil is diminished. This has been demonstrated for P-saturated soils, where P, although generally regarded as an immobile ion, was reported to be lost by subsurface pathways (Breeuwsma and Silva, 1992). Both study sites Kassow and Ceveiro were classified as below, whereas Warberg was found to be well above the optimum range with respect to their P status (Chapter 2.1.2). Thus, it is proposed that the degree of spatial speciation of P in agricultural soils is controlled by firstly, the fertility of the soil and secondly, by the soil texture.

The variability of soil attributes is generally lower in static rather than in dynamic properties (Wilding, 1985; Goderya, 1998). Cahn (1994) even suggested that increasing variability may relate to increasing nutrient mobility. A comparison of the main soil types with respect to their relative standard deviation (RSD %) showed that the overall variation in soil P decreased with increasing extraction force of the extractant used. Thus, lowest variation was found for the sparingly available, whereas highest variation was found for the readily available P pool (Tab. 4.2).

Tab 4.2: Comparison of study sites with respect to their RSD (%) values for individual P fractions.

	Study site			
P fraction	**Kassow**	**Warberg**	**Ceveiro**	
	Cambisol	**Luvisol**	**Paleudult**	**Udorthent**
$CaCl_2$-P	61	71	861	276
AAC-P	59	36	221	148
Resin-P	n.a.	n.a	193	109
WH-P	30	55	231	148
AR-P	17	29	101	66

n.a. = not available

In unfertilised systems the total P content is a primary property of the soil (Hedley et al., 1995). As such its distribution is mainly a function of weathering processes (Smeck, 1973). In fertilised systems it is the sum of the natural background concentration in the soil and past fertiliser applications. In either system total P, and therefore, the sparingly available P pool, is relatively inert to short-term environmental impacts, such as recent fertiliser placement or changes in tillage practices. In a comprehensive review Beckett and Webster (1971) showed that the sparingly available P pool was little affected by management, whereas the reversibly available P pool was most affected by management.

The results of the present research work demonstrated clearly that the distribution of the reversibly available P pool was strongly controlled by parent material and geomorphology of the study sites. Soil texture classes in Warberg and parent material in Ceveiro differed significantly with respect to their total P concentration (Chapter 3.3.2). Although no correlation between total P and soil texture classes and or clay content was evident in Kassow, AR-P was found to increase along the topographic gradient indicating that it was transported as particulated P by surface erosion (Chapter 3.3.3). The effect of particle erosion on the sparingly available P pool was further expressed by the anisotropic distribution of this pool (Chapter 3.4.1, Tab. 3.8). The same phenomenon was found for the Ceveiro study site where the direction of maximum spatial continuity of total P coincided with the direction of the maximum topographic gradient, indicating that total P accumulated in footslope positions (Chapter 3.4.3).

Peinemann and Brunotte (1982) showed for Loess derived soils in Lower Saxony, that the distribution of nutrients was linked to changes in texture followed by surface erosion. The strong effect of surface erosion on the distribution of total P lead Steegen et al. (2000), who investigated the spatial distribution of total P in a Loess Belt in central Belgium, to the suggestion that one use total P as a tracer for long term soil erosion. However, this hypothesis seems not applicable for the Luvisol in Warberg as soil P was not found to be translocated down the topographic gradient (Chapter 3.3.3).

The high silt content of Loess derived soils makes these soils prone to surface crusting, which causes erosion and subsequent loss of the A-horizon (Catt, 2001). Severe erosion was evident at least in Warberg at fields BB and M3, which exhibited a higher LS factor as well as a larger percentage of clay content in the topsoil. Generally, in loess derived soils clay illuviation results in depletion of the A-horizon with respect to clay. High clay contents in the topsoil are thus indicative of soil erosion and subsequent loss of the material from the A-horizon (Altemüller, 1957). In Loess, surface erosion will usually decrease the depth of decalcification. This was visually evident as carbonate accretion so called “Loesskindel” in the topsoil layer of fields BB and M3.

It was shown that the sparingly available P pool increased with increasing carbonate content of the soil (Chapter 3.2.2, Fig. 3.7). As for these soil samples the readily available P pool was decreased (Chapter 3.2.2, Fig. 3.7) it is suggested that on eroded slope positions “Loesskindel” resulted in a re-precipitation of fertiliser P as low-soluble Ca-phosphates. Thus surface erosion, rather than transporting particulated P down the topographic gradient, resulted in an accumulation of total P in upslope position. This is further supported by the findings that for fields BB and M3 the sparingly available P pool was found to increase with increasing slope (Chapter 3.3.3, Fig. 3.18).

Nevertheless, the spatial distribution of soil P revealed a strong trend for all P pools which coincided with the prevailing direction of tilling (Chapter 3.4.2, Tab. 3.10). Although this direction did not coincide with the main topographic gradient of the sub-catchment the findings indicate that tillage erosion (soil movement by tillage equipment), caused a higher variability of P in soil samples perpendicular to the tillage line than horizontally to it. These conclusions are supported by a recent study by Quine and Zhang (2002) who found soil redistribution by tillage a major contributor to the spatial variation in soil properties.

It was previously reported that the spatial distribution of the sparingly available P pool is controlled by recent fertiliser placement. Mallarino (1996) showed for untilled soil that repeated banded fertiliser application resulted in periodic spatial trends of Bray-I P. For site specific P management Schepers et al. (2000) pointed out the importance of past fertiliser history. At Kassow, variable rate P fertilisation, aiming at decreasing the variability of the reversibly available P pool, was carried out in 1994 and 1995. A comparison between the within-field variation of the pool in 1993 (DL-P) and in 1996 (AAC-P) showed that with a RSD of 25 % the overall variation was lower in 1993.

A comparison of the semi-variogram models further revealed that for 1993, despite the larger grid size of 100 m, the small scale variance, indicated by the nugget variance, was much lower than in 1996 (Fig. 4.5).

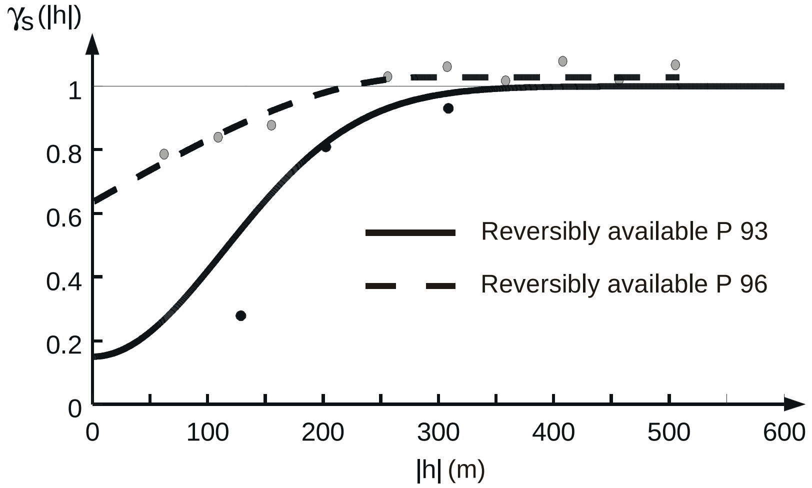

Fig. 4.5: Omnidirectional standardised semi-variogram models for the reversibly soil P pool in the Luvisol in Kassow for 1993 and 1996).

The spatial continuity of the sparingly available P pool was shown to be caused by surface erosion, evident in the anisotropic distribution of the total soil P pool. In contrast the reversibly available P pool in 1996 did not show any reflection of redistribution by erosion, as the spatial distribution did not show a preferential direction. Thus it is presumed that the increased small scale variation was caused by the 1996 erosion event, whereby the overall omnidirectional distribution reflects the variable rate fertiliser regime.

However, considering the overall high variability of the study site the small scale variance of the reversibly available P may also be attributed to other spatially distributed factors, for instance soil moisture, soil temperature, quality and quantity of organic matter. The importance of organic matter in the storage and release of moisture and plant available nutrients increases as the percentage clay content decreases (Hunsaker et al., 1991). Soil moisture is controlled by the non-uniformity in the physical soil factors, along with the supply of moisture. Soil moisture is crucial to plant growth and thus to the uptake of P and replenishment (Power et al., 1961), but also for the diffusion of readily plant available P to the roots and thus for the supply of the reversibly soil P pool.

In Warberg differentiated P management practice resulted in significant differences between fields with respect to their P status (Chapter 3.3.1, Fig. 3.13). This was more strongly reflected in the soluble and the labile P pool, whereas WH-P and total P were found to only differ in fields M1 and M2.

In Ceveiro, with the exception of Resin-P the P fractions representing the reversibly available P pool, were found to have no preferential direction and a significant smaller spatial continuity than the sparingly available P pool. Anion exchange resins are thought to be more sensitive to the soil P sorption capacity factor than acidic extractants such as AAC and WH (Oliveira et al*.,* 2000). McKean and Warren (1996) found that in successive resin extractions, the proportion of labile P in a single extraction was inversely related to the soils P sorption capacity factor. This could explain the observed distribution pattern of Resin-P and its high correlation with the total P pool in the Udorthent (Chapter 3.2.3) as well as its much lower within-field variation when compared to AAC-P and WH-P (Chapter 4.3, Tab. 4.2). This could also indicate that this method might not be suitable to evaluated the sparingly available P pool (see Chapter 4.6).

The low correlation between the AAC-P, WH-P and Resin-P was argued to indicate a large variation of the reversibly available P pool with respect to its P species (Chapter 3.2.2). In addition, due to the very high variation of soil P for different land-use systems (Chapter 3.3.1, Fig. 3.14) and the lack of information on individual sugar-cane fields it was not possible within the frame of this work to investigate the effect of land-use on the sparingly available P pool. However, considering that the average size of sugar-cane fields within this region is several 100 ha (Sparovek, 2000) it is suggested that the short ranges of autocorrelation observed for AAC-P and WH-P reflect the low fertility of the soils within the Ceveiro study site, which is only raised by recent fertiliser inputs in form of mineral P fertiliser or animal droppings.

The readily available P pool, is often used as an indicator of the potential runoff of agricultural soil P into receiving water bodies and thus as an indicator of potential algae available P (Haygarth et al., 1997; Sharpley et al., 2000). While crop selection and management are both important factors in the depletion of the readily available P pool, under similar management conditions, the specific adsorption capacity of the soil (capacity factor) is assumed to control the rate of P release into solution (Mc Dowell and Sharpley, 2002).

In Kassow, the influence of soil texture on the readily available P pool was reflected in a very strong trend perpendicular to the direction of tillering. The trend was caused by extreme values, together with a soil texture gradient along the west-easterly axis of the field. Detrending revealed a spatial isotropic continuity which coincided with the range of the loamy sand fraction (Chapter 3.4.1 Tab. 3.8 & Tab. 3.9).

In Warberg, although no spatial speciation of the individual P pools occurred, the readily available P pool was found to be negatively correlated with the adsorption capacity of the soil (Chapter 3.2.3, Fig 3.11). It is assumed that due to the relative homogeneous soil texture of the Loess derived soil, the effect of carbonates was superimposed on the effect of soil texture. This is reflected by the similar ranges of the semi-variogram models for $CaCl_2$-P (Chapter 3.4.2, Tab. 3.10) and soil pH (Chapter 2.1.2, Tab. 2.5).

4.4 Evaluation of Variography as a tool to describe spatial speciation

For the evaluation of a variability study, based on attributes expressed as a continuous function of numerous, scale-variable influencing factors it is essential to understand that the results produced are dependent on scale and frequency of observations (Webster and Oliver, 1990). At the landscape scale and over times of millennia and longer, hypotheses of soil genesis exist, which state how geology and climate are supposed to cause variation in soil. For the scale of individual fields and over times of minutes, hours, days and months, one may use laws of physical processes, expressed quantitatively in terms of the Debye-Hueckel theory and Fick’s law (for example de Jong et al., 2002). Using variography as a tool to study the spatial continuity of soil parameters, one has to keep in mind that the results of a variogram model strongly depend on the sampling area and the distance between sampling points.

Several studies have compared soil sampling techniques and shown that estimates of spatial variability of soil nutrient supplies and other soil properties are strongly affected by the scale of sampling (Franzen and Peck, 1995; Wollenhaupt et al., 1994; Mallarino, 1996). Gajem et al. (1981), convincingly demonstrated that for nine physical soil parameters the range of spatial dependency increased tenfold as the sample separation and transect length increased by an order of magnitude.

The large nugget values for the sparingly available P pool in the loess derived soil from Warberg (Chapter 3.4.2, Tab. 3.10) and for the reversibly available P pool in the sandy soil from Kassow (Chapter 3.4.1, Tab 3.8) indicate that the spatial variation of these pools was smaller than the scale of sampling. Nevertheless, it is commonly found in environmental sciences that while we examine a system at increasingly fine spatial scales, the problems of understanding and modelling its behaviour become increasingly difficult.

Addiscott (1998) refers to this phenomenon as “scale-dependent decoherence”. In the case of agriculture scale-dependent decoherence implies an optimal scale of operation within any field, but this will not necessarily be at the finest scale, which can technically be managed. The main objective of the present research work was to test the hypothesis that the distribution of functional soil P pools within agroecosystems are not random, but display a spatial continuity that can be estimated using geostatistical methods (Chapter 1). For all study sites variogram models revealed that the functional soil P pools, the readily available, the reversibly available and the sparingly available P pool, can be described by an autocorrelation function which was quantitatively assessed (Chapter 3.4.). Furthermore, it was possible to allocate environmental processes that contributed to these autocorrelation functions. The main environmental factors that controlled the spatial distribution of individual P pool were: soil texture in the case of the readily available P pool, recent fertilisation in the case of the reversibly available P pool and primary soil properties in the case of the sparingly available P pool (Chapter 4.3). Thus from the results of this research work it is evident that variography provides relevant information about the spatial variation of different P pools.

4.5 Evaluation of geostatistical methods for the assessment of soil analysis methods

According to McBratney and Whelan (1999) most agricultural fields are managed in conformity with a risk-averse "null hypothesis"[1] that they may each be regarded effectively as a uniform resource. Management strategies are based on experiments conducted on small plots, in experimental designs which estimate a statistical abstraction: the mean response across the field (Schnug et al., 1998).

In the introductory chapter of this work the necessity of the implementation of balanced P fertilisation regimes was emphasised, whereby the fertiliser rate is calculated from the balance between the natural supply by soil and environment, the nutrient demand of the crop and inevitable losses to the environment (Vermeulen et al., 1998). Even under the assumption that precise fertiliser rates could be calculated for any combination of soil fertility, environmental losses and yield expectations, the variation of soil parameters in space and the common assumption of the "null hypothesis" (McBratney and Whelan, 1999) will inevitably cause deficiency and surplus to be found side by side (Haneklaus and Schnug, 2002). Thus, the key to achieve balanced fertilisation is to move away from the "null hypothesis", that soils are uniform resources, and to account for the spatial variation in soil within fields in management.

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[1] Given uncertainty in space and time, uniform within-field treatment is an optimal strategy (McBratney and Whelan, 1999).

The problem of spatial variability of soil fertility, acknowledged since the dawn of farming itself (since ca. 10.000 BC; Graichen, 1997), led to the development of Site-Specific Nutrient Management (SSNM) (Haneklaus and Schnug, 2002). It was in the last century of the second millennium that the breakthrough of SSNM as a strategy to address soil variability in practical agriculture succeeded, because of three major developments: geostatistics, powerful computing and data storage systems and satellite positioning and navigation (Schnug et al., 1985; Lamp and Schnug, 1987).

Despite these technological breakthroughs a pre-requirement of a successful SSNM is the generation of digital agro-resource-maps (DARMs, Schroeder et al., 1997), by collecting soil samples and subsequent chemical analyses. Besides the need to meet the common quality standards for soil analysis, which are: precision, accuracy and validity (for example Hanlon, 1996; Houba et al., 1996; Schnug, 1996b), soil tests employed for the creation of DARMs, have to reflect the spatial autocorrelation with minimum sampling efforts, while being highly sensitive to the small scale variation of soil fertility parameters. These two criteria would be reflected in a semi-variogram model with a long range and a low nugget effect (Chapter 2.6.1, Fig. 2.15).

Following the general understanding, that the more mobile the soil parameter under investigation, the larger the observed small-scale variation and the lower the range of spatial continuity, one could argue that a soil test method, like the AR-method, analysing a less mobile nutrient pool would suit the above criteria the best. When compared to the other three extraction methods used in this work the AR-method displayed the longest ranges and lowest nugget effects, for the Kassow and the Ceveiro study site, but not in Warberg (Chapter 3.4, Tab.3.8, Tab.3.10,Tab.3.11). Considering the overall homogeneity of the Loess derived soil at Warberg and the very low RSD value for AR-P (19 %) the large nugget variance appears to be a reflection of random variation. In contrary, the large nugget variance obtained for AAC-P and $CaCl_2$-P in Kassow (Chapter 3.4.1, Tab 3.3) indicated that more than 50 % of the observed variance (RSD 59 % and 61 %, respectively) occurred between sampling points. Although, the data set does not give any insight into the nature of this unexplained variance, it is likely that, due to the magnitude of the total observed variance, it was not random, but spatially correlated. Under this assumption, the results show that the chosen sampling distance of 50 m was not sufficient in order to account for the spatial pattern of AAC-P and $CaCl_2$-P in Kassow.

From the presented results it is evident that the spatial structure of soil test methods is not only nutrient specific, but also site specific. It follows, that the creation of true DARMs, rather than being a question of selecting an appropriated soil test method, is a question of choosing the right sampling scheme.

The rationale of this research work was partly derived from the understanding that increasing sampling density increases the accuracy of the created DARM, but in most cases is not economically feasible or sustainable for farmers (Lowenberg-DeBour and Boehlje, 1996). Thus, the question of selecting an appropriated sampling scheme has to move away from the scaling issue, but needs to address how interpolation of soil tests can be improved using auxiliary information about the behaviour of the nutrient in question.

There are two fundamentally different approaches to do so: firstly, design based (e g. stratified random sampling) and secondly model-based (e.g. geostatistical modelling) sampling strategies (Brus and de Gruijter, 1997). Either approach is based on a strong relationship between the nutrient in question and surrogates or easy-to-measure morphological properties (e.g. McKenzie and MacLeod, 1989; McKenzie et al., 1991; Haneklaus and Schnug, 2002) or topographic attributes (e.g., Odeh et al., 1994; Odeh et al., 1995; Haneklaus and Schnug, 2002). The model based approach utilises either regression-kriging or cokriging models (Odeh et al., 1994), whereas the design based approach (directed sampling, Schnug et al., 1994 and 1998; Pocknee et al., 1996) uses a more subjective and intuitive approach to divide any field into smaller units. Soil samples collected at random from within each zone are bulked together and analysed to provide an average sample value for each unit (Pocknee et al., 1996).

In the present research work it was shown that only for the Ceveiro study site, where the distribution of P was found to be mainly a function of pedogenesis, the GLM, relating morphological and topographical factors to the distribution of soil P, explained more than 50 % of the variation in soil P. In the two German sites, Kassow and Warberg, management of the fields appeared to be the dominant factor overriding the effect of pedogenesis (Chapter 3.3). Thus, a model based approach, utilising regression-kriging or cokriging models based on correlation between soil P and topographic attributes, has to be evaluated as not suitable for generating soil P distribution maps in fields with a long term fertiliser and cropping history.

However, the results of the present work clearly demonstrates that environmental factors, which controlled the spatial distribution of each functional soil P pool, can be identified and thus, could be used to plan a design based sampling approach.

Although so far model based sampling has been proven to be more accurate than design based sampling when mapping soil P (Peck and Soltanpour, 1990; Franzen and Peck, 1993; Bronson et al., 2000; Mallarino and Wittry, 2000) it is implied that these results reflect inappropriate design based sampling schemes as most studies employed either landscape- or soil type based soil sampling strategies to map the spatial variability of the reversibly available P pool.

In the present work it was shown that only the spatial distribution of the sparingly available P pool was controlled by parent material and topography, but the spatial distribution of the readily available P pool by the degree of ageing of fresh soil P fractions, precipitated from application of soluble fertiliser. Under the assumption of uniform fertiliser application, the degree of ageing is mainly controlled by the soil pH and the presence of bases of calcium, aluminium and iron (Sample et al., 1980). Thus it is suggested that soil type units are a reasonable indicator for the spatial variation of the degree of ageing of fresh soil P fractions, precipitated from application of soluble fertiliser. Considering that the accumulation and ageing of fertiliser P in the soil is not only a function of the soil properties and the amount of fertiliser applied, but also of the amount of soil P removed by crops, it is proposed that a design based approach has to incorporate both: the soil type units and spatially dependent plant uptake. The utilisation of yield maps for monitoring within-field nutrient variation was already proposed by Schnug et al. (1994), who introduced the concept of monitoring “equifertiles”, which are defined areas, where crop yield, relative to the mean yield, is consistent over years.

The aim of a survey should strongly influence the statistical approach (Domburg et al., 1994). It is often assumed that to answer a “where” approach is the ultimate goal of precision agriculture. However, if precision agriculture is to be implemented by farmers, the main goal has to be its economical soundness (Haneklaus and Schnug, 2002). In the light of the above discussion it appears that geostatistical methods, evaluating the spatial continuity of soil P tests, can only be used to create accurate DARMs if the sampling density is large enough to account for small scale variability. However, this is contradictory to the requirement that the spatial autocorrelation has to be reflected with minimum sampling effort.

In the previous chapter (Chapter 4.4) the concept of “scale-dependent decoherence” (Addiscott, 1998) was introduced. This implies that an optimal scale of operation within any field will not necessarily be at the finest scale that can technically be managed. It is proposed therefore that, because of economic considerations, geostatistical methods do not allow for the creation of suitable DARMs in the case of P. This is despite the technological breakthroughs of precision agriculture, which allow variable rate fertiliser strategies to respond to soil variability of some arbitrarily fine scale. Despite the widespread use of geostatistical methods for SSNM, a design based approach, employing classical statistics, should be employed. This would shift the paradigm of “where” to “how much” (Domburg et al., 1994), given that pre-information about the behaviour of the nutrient in question is available. Heuvelink (1997) in a reply to Brus and de Gruijter’s (1997) paper on design-based versus model-based sampling, states that if the approach of a survey is to answer a “how much” request a design based approach is generally the most suitable approach.

It is therefore proposed that future research needs to investigate the suitability of design based sampling strategies based on past fertiliser history, soil types and equifertiles for mapping the reversibly available P pool.

5. Summary

The main objective of the present research work was to investigate the spatial dynamics of soil P pools in agroecosystems. Apart from increasing the knowledge of P dynamics in the environment, the relevance of this work is given by the implementation of SSNM via Precision Agriculture and balanced P fertilisation regimes, in order to achieve a minimum environmental impact of nutrient use in agriculture.

The investigations were conducted at three study sites: Kassow (78 ha; n = 190; E12° 06', N53° 10'), Warberg (40 ha; n = 404; E10°54', N52°10') and Ceveiro (2200 ha; n = 300; 47º 47'W, S22º 40'), which differed in climate, parent material, topography, P fertiliser regime and land management. P was analysed using four extraction methods which varied with respect to their extraction force. Extractants used were: aqua regia (AR), nitric acid (WH), ammonium acetate (AAC) and calcium chloride ($CaCl_2$). Special emphasis was placed on the employment of variography as a tool to evaluate the chemical reactivity of soil P with site specific environmental factors and the subsequent formation of geochemical species that display different spatial dependencies.

The main results of the work presented here were:

1) Based on the extraction methods employed in the two temperate soils (Kassow, Warberg), the total soil P reserve was partitioned into three functional P pools: readily available (P extracted by $CaCl_2$, 1-2 % of the total AR-P), reversibly available (P extracted by AAC, 17 % of the total AR-P) and sparingly available (P extracted by AR minus P extracted by $CaCl_2$ & AAC, 81-82 % of the total AR-P).

2) The high degree of chemical weathering and subsequent high anion adsorption capacity of the two tropical soils (Ceveiro) did not allow an accurate assessment of the readily available P pool in these soils. 1-2 % of the total P reserve was estimated to be readily available, whereas 3–13 % was allocated to be in reversibly available form (P extracted by AAC, WH).

3) The overall variance in soil P decreased with increasing extraction force of the extractant used. The lowest variance (RSD 17–101 %) was found for the sparingly available, whereas highest variation was found for the readily available P pool (RSD 61–861 %).

4) All investigated P fractions, representative of functional P pools, displayed spatial autocorrelation, which was quantitatively analysed using variography. In Kassow, functional P pools did not only differ with respect to their spatial ranges, but also in their distribution pattern and strength of the autocorrelation. The ranges of P fractions decreased in the order: AAC-P > AR-P/WH-P (1. structure) > AR-P/WH-P (2. structure) > $CaCl_2$. In Warberg functional P pools were not found to differ significantly in their spatial ranges (~100 m), but in the strength of their autocorrelation. In Ceveiro, the functional P pools were found to differ significantly, with the reversibly available P pool displaying the shortest range (57–70 m) and the sparingly available P pool the longest (280 m, 1. structure; 808 m, 2. structure).

5) The derived semi-variogram models, on average, revealed a small scale variation (nugget variance) of about 30 % of the total observed variance, which could not be explained by the semi-variogram model. It is assumed that the high nugget variance was caused by spatially dependent plant uptake and thus, by growth factors which were not investigated in the present work.

6) Large nugget values for the sparingly available P pool in the Loess derived soil (Warberg) and the reversibly available P pool in the sandy soil (Kassow) indicated, that more than half of the observed variance in these pools was contributed by a spatial variation that was smaller than the scale of sampling (Warberg: 30 m x 30 m; Kassow: 50 m x 50 m).

7) The degree of spatial speciation of P, that was explained by the variogram models, was found to be controlled by firstly, the P status of the soil and secondly, by soil texture.

8) The main environmental factors that controlled the spatial distribution of individual P pools were: soil texture for the readily available P; degree of ageing of fresh soil P fractions,

precipitated from application of soluble fertiliser P, for the reversibly available P; and primary P-minerals and geomorphology for the sparingly available P.

The results of this work reveal that multivariate geostatistical analysis of P fractions offer a powerful way of predicting local functions of spatial speciation of P in soils. Thus, studies that investigate the biogeochemical cycling of nutrients should be evaluated in the context of site-specific soil characteristics. However, for the mapping of soil P distribution for SSNM the accuracy needed is only achievable with a high sampling density, which makes this method uneconomic. It is therefore proposed to employ design based sampling strategies. As suitable strata for mapping the spatial distribution of the readily available P pool soil texture is suggested, for mapping the spatial distribution of the reversibly available P pool soil type units and equifertiles and for mapping the spatial distribution of the sparingly available P pool soil type and landscape units are suggested.

Zusammenfassung: Einflussfaktoren der raeumlichen Variabilitaet von Phosphat-Bindungsformen in landwirtschaftlichen Boeden

Ziel der vorliegenden Arbeit war es, die raeumliche Dynamik verschiedener Bindungsformen von Phosphor (P) in landwirtschaftlichen Boeden zu untersuchen. Die Relevanz dieser Arbeit leitet sich aus der Umsetzung von SSNM mittels Precision Agriculture und bilanzorientierter Duengung ab, mit dem Ziel der Minimierung von Umweltbeeintraechtigungen durch in der Landwirtschaft eingesetzte Naehrstoffe.

Die im Rahmen dieser Arbeit vorgenommenen Untersuchungen wurden an drei Standorten durchgefuehrt: Kassow (78 ha; n = 190; E12° 06', N53° 10'), Warberg (40 ha; n = 404; E10°54', N52°10') und Ceveiro (2200 ha; n = 300; 47º 47'W, S22º 40'). Die Standorte unterschieden sich in Klima, Ausgangsgestein, Topographie, P-Duengung und Feldbearbeitung. Die P-Gehalte wurden mit vier Extraktionsmethoden unterschiedlicher Extraktionskraft bestimmt: Koenigswasser (AR), Salpetersaeure (WH), Ammoniumacetat (AAC) und Calciumchlorid ($CaCl_2$).

Besondere Beachtung fand in dieser Arbeit der Einsatz von Geostatistik (Variogramm Analyse) als Mittel zur Evaluierung der Beziehungen zwischen chemischer Reaktivitaet des Bodenphosphates und ortsabhaengigen Umweltfaktoren (spatial speciation).

Die Arbeit erbrachte die folgenden Ergebnisse:

1) Unter Beruecksichtigung der angewandten Extraktionsmethoden konnte der P-Gesamtgehalt der Boeden in gemaessigtem Klima (Kassow, Warberg) in drei funktionale P Pools eingeteilt werden: leicht verfuegbares P (P extrahiert mit $CaCl_{2,}$ 1-2 % vom gesamten AR-P), reversibel verfuegbares P (P extrahiert mit $AAC_,$ 17 %) und wenig verfuegbares P (P extrahiert mit AR minus P extrahiert mit $CaCl_2$ & $AAC_,$ 81-82 %).

2) Der hohe Verwitterungsgrad der tropischen Boeden (Ceveiro) behinderte eine genaue Bestimmung des leicht verfuegbaren P Pools. 1-2 % des P-Gesamtgehaltes wurden als leicht verfuegbar, und 3–13 % als reversibel verfuegbar (P extrahiert bei AAC, WH) geschaetzt. Der wenig verfuegbare Anteil belief sich auf 85-96 %.

3) Die Varianz der Gehalte an unterschiedlichen P-Bindungsformen verringerte sich mit zunehmender Extraktionskraft der Methode. Die geringste Varianz (RSD 17–101 %) wies der wenig verfuegbare, die hoechste (RSD 61–861 %) der leicht verfuegbare P Pool auf.

4) Alle untersuchten P Fraktionen zeigten eine raeumliche Autokorrelation, die mittels Geostatistik quantitativ bestimmt werden konnte. In Kassow unterschieden sich funktionale P Pools hinsichtlich ihrer Reichweite, sowie in der Staerke der Autokorrelation. Die Reichweiten nahmen in folgender Reihenfolge ab: AAC-P > AR-P/WH-P (1. Struktur) > AR-P/WH-P (2. Struktur) > $CaCl_2$. In Warberg unterschied sich die raeumliche Verteilung der funktionalen P Pools hinsichtlich ihrer Reichweiten (~100 m) nicht, aber in der Staerke der Autokorrelation. In Ceveiro hingegen unterschied sich die raeumliche Verteilung funktionaler P Pools signifikant, wobei der reversibel P Pool die kuerzeste Reichweite (57–70 m) und der langsam verfuegbare P Pool die laengste Reichweite (280 m, 1. Struktur; 808 m, 2. Struktur) aufwies.

5) Die abgeleiteten Variogrammodelle zeigten in der Regel einen kleinraeumigen Variabilitaetsanteil (Nugget-Varianz) von annaehernd 30 %, der sich nicht aus den Variogrammodellen erklaeren lies. Es wurde angenommen, dass diese relativ hohen Nugget-Varianzen durch ortsgebundene Pflanzenaufnahme und somit durch Umweltfaktoren, die im Rahmen der vorliegenden Arbeit keine Beruecksichtigung fanden, verursacht wurden.

6) Hohe Nugget-Effekte fuer den langsam verfuegbaren P Pool im Loessboden (Warberg) und fuer den reversibeln P Pool im sandigen Boden (Kassow) wiesen darauf hin, dass mehr als die Haelfte der gemessenen Varianz durch eine raeumliche Varianz bedingt wurde, deren Reichweite kleiner war als der Probennahmeabstand (Warberg: 30 m x 30 m; Kassow: 50 m x 50 m).

7) Der Grad der raeumlichen Variabilitaet zwischen P-Bindungsformen, die durch angepasste Variogrammodelle erklaert werden konnte, wurde in erster Linie durch die P-Versorgung des Bodens und damit durch das P-Duengeregime bestimmt. Je geringer die P-Versorgung

war, desto staerker war der Einfluss der Bodentextur und damit die P-Absorption des Bodens.

8) Hauptfaktoren der raeumlichen Verteilung der einzelnen P-Bindungsformen waren: die Bodentextur (leicht verfuegbarer P Pool), Alterung der Umsetzungsprodukte wasserloeslicher P-Duenger (reversibel verfuegbarer P Pool) und das Vorkommen primaerer P-Mineralien, sowie die Geomorphologie (langsam verfuegbarer P Pool).

Die Ergebnisse der vorliegenden Arbeit zeigen, dass eine multivariate, geostatistische Analyse ein grosses Potenzial zur Vorhersage lokaler Funktionen der raeumlichen Variabilitaet von P-Bindungsformen bietet. Hieraus ergibt sich die Notwendigkeit, Naehrstoffkreislaeufe in Agraroekosystemen im Zusammenhang mit ortsabhaengigen Bodeneigenschaften zu untersuchen.

Fuer die Zielsetzung einer P-Kartierung als Grundlage fuer SSNM zeigt sich jedoch, dass die erforderliche Genauigkeit mit diesem Analyseverfahren nur mittels einer sehr hoher Probennahmedichte erreicht werden kann. Aus oekonomischer Sicht ist dieses Verfahren daher als ungeeignet einzustufen. Auf Grund der Ergebnisse der vorliegenden Arbeit wird als Alternative das „directed sampling“ vorgeschlagen. Als geeignete Strata fuer die Auswahl von Probennahmestellen ergeben sich fuer den leicht verfuegbaren P Pool die Bodentextur, fuer den reversibel verfuegbaren P Pool Bodentypen und sogenannte Equifertilen und fuer den wenig verfuegbaren P Pool Bodentypen und Landschaftszonen.

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7. Appendix

Tab. A.1: P concentrations of reference material analysed in fivefold replication using $CaCl_2$, AAC, WH, AR, H_2O, Bray I and Olsen.

Material	Replicate	AR	CAL	WH	AAC	Bray I	Olsen	$CaCl_2$	H_2O
					mg kg^{-1}				
Ceveiro1	1	142	16.7	25.7	17.3	33.6	14.5	0.17	5.22
Ceveiro1	2	144	16.7	26.01	16.9	35.01	14.4	0.13	5.48
Ceveiro1	3	144	17.3	25.9	17.08	34.9	13.6	0.13	5.83
Ceveiro1	4	144	16.9	26.2	17.08	34.5	12.9	0.13	5.40
Ceveiro1	5	144	17.9	25.2	16.9	34.6	13.01	0.12	5.57
Ceveiro2	1	134	4.38	5.06	3.04	9.75	7.88	0.03	4.79
Ceveiro2	2	136	3.96	4.63	2.93	9.22	6.95	0.04	4.44
Ceveiro2	3	140	3.76	4.89	2.93	9.43	8.15	0.04	4.96
Ceveiro2	4	138	3.76	4.89	2.93	9.54	7.21	0.03	4.87
Ceveiro2	5	136	3.76	5.06	2.93	9.33	7.25	0.03	4.70
Ceveiro3	1	421	6.47	11.0	5.97	17.7	13.6	0.03	8.53
Ceveiro3	2	421	6.26	11.07	5.97	17.9	14.1	0.03	8.70
Ceveiro3	3	427	6.47	10.9	6.71	18.6	14.3	0.03	8.44
Ceveiro3	4	425	6.47	11.2	6.08	17.8	14.4	0.03	8.53
Ceveiro3	5	429	6.26	10.8	6.08	17.7	13.8	0.03	8.62
Warberg	1	466	85.5	149	121.6	92.2	29.7	0.72	11.2
Warberg	2	458	84.5	158	121.6	89.09	28.0	0.72	10.8
Warberg	3	470	88.7	147	121.6	88.04	29.06	0.74	11.01
Warberg	4	470	84.5	148	120.5	84.9	28.8	0.75	11.0
Warberg	5	499	84.5	152	120.5	88.04	29.6	0.72	11.0
Kassow	1	482	68.8	181	85.9	148.8	31.7	4.08	16.5
Kassow	2	478	65.7	179	82.8	145.7	29.7	4.16	15.6
Kassow	3	482	63.6	187	81.8	148.8	31.7	4.26	15.6
Kassow	4	470	66.8	185	80.7	145.7	30.5	4.15	15.7
Kassow	5	478	63.6	179	95.4	145.7	30.5	4.11	15.9

Tab. .A.2: Results of chemical soil analysis for grid samples from Kassow (E12º06’, N53º 10’).

Sample	**Easting m**	**Northing m**	**AR-P mg kg^{-1}**	**WH-P mg kg^{-1}**	**AAC-P mg kg^{-1}**	**CAL mg kg^{-1}**	**CaCl$_2$-P mg kg^{-1}**	**pH**	**C$_{tot}$ %**	**CaCO$_3$ %**	**Clay %**	**Rb mg kg^{-1}**	**Fe g kg^{-1}**	**Zn mg kg^{-1}**
1	4505653	5971261	575	366	120	147	3.03	6.80	1.14	0.85	9.18	19.3	n.a.	5.31
2	4505617	5971292	495	278	84.5	79.2	3.60	6.69	0.82	0.55	7.09	15.7	0.93	4.80
4	4505541	5971354	497	237	61.5	78.0	1.57	7.05	1.06	1.43	11.1	22.3	n.a.	4.99
5	4505502	5971385	483	227	69.1	79.2	0.70	6.78	0.91	0.91	9.00	18.8	0.88	4.94
6	4505466	5971413	445	151	20.7	24.3	0.99	5.71	0.89	0.21	7.09	15.9	n.a.	3.36
7	4505428	5971444	497	195	23.6	29.5	1.70	4.94	1.16	0.13	8.27	17.7	0.78	4.03
8	4505391	5971472	507	271	52.8	74.9	1.21	5.90	1.00	0.17	7.37	16.2	n.a.	3.58
9	4505355	5971503	496	169	24.3	32.3	1.82	4.70	0.81	0.33	8.64	18.4	0.78	3.74
10	4505317	5971530	502	214	31.4	38.6	4.03	4.86	0.90	0.50	9.27	19.1	n.a.	4.09
11	4505281	5971563	471	221	61.0	37.8	4.36	5.03	0.88	0.67	9.00	18.7	0.83	5.28
12	4505243	5971592	491	220	62.9	49.4	2.46	5.90	0.87	0.55	8.64	18.5	n.a.	4.78
13	4505207	5971621	549	269	86.1	84.0	2.69	6.18	0.97	0.29	9.72	20.0	0.94	4.57
14	4505122	5971618	677	399	149	146	5.57	6.26	1.18	0.50	10.4	21.0	n.a.	6.29
15	4505162	5971585	504	348	77.7	79.2	6.35	6.24	0.87	0.25	9.18	19.1	0.93	4.10
16	4505200	5971556	643	435	61.0	126	3.79	6.91	1.62	0.10	10.0	20.7	n.a.	5.06
17	4505236	5971527	621	356	123	133	4.93	6.88	0.98	0.50	11.7	23.5	1.19	5.35
19	4505310	5971466	511	258	41.3	48.6	4.70	5.55	0.91	0.34	9.18	19.3	0.99	4.27
20	4505346	5971437	557	263	37.4	51.4	5.30	4.45	0.78	0.29	7.64	16.5	n.a.	3.70
22	4505421	5971379	500	325	100	79.6	4.92	6.03	0.80	0.54	8.09	17.5	0.75	5.05
23	4505457	5971350	489	300	49.1	42.6	6.00	5.45	0.93	0.13	7.64	17.1	n.a.	4.77
24	4505493	5971319	498	309	121	110	5.61	6.45	0.92	0.78	10.0	16.7	0.85	5.97
26	4505570	5971256	651	355	87.6	93.2	5.23	6.21	1.09	0.12	5.82	20.6	n.a.	6.00
27	4505605	5971231	579	385	107.9	82.0	8.36	5.76	0.89	0.08	9.54	13.6	0.70	5.69
28	4505553	5971201	835	596	159	129	12.8	5.56	1.11	< 0.01	11.1	19.6	n.a.	7.44
29	4505518	5971232	546	287	118	111	11.4	6.05	0.88	0.12	10.6	22.1	n.a.	4.88
30	4505482	5971261	583	276	62.2	54.2	7.17	5.64	1.13	0.33	8.09	21.5	0.92	6.00

Table A.2 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
31	4505445	5971292	509	291	95.5	93.2	4.45	6.44	0.85	0.08	9.63	17.5	n.a.	4.77
32	4505408	5971324	509	265	57.0	65.3	5.83	6.06	0.90	0.16	7.37	20.0	1.10	4.55
33	4505370	5971354	488	246	33.0	49.4	3.47	4.50	0.73	0.08	8.27	16.3	n.a.	3.44
34	4505332	5971383	579	289	39.6	68.5	3.54	4.15	0.73	0.12	9.45	17.6	0.76	2.76
35	4505293	5971413	453	230	40.2	42.6	3.79	4.74	0.85	0.06	9.81	19.6	n.a.	4.18
36	4505256	5971442	548	270	46.2	52.2	5.72	4.72	0.91	1.63	9.45	20.2	0.79	4.49
37	4505220	5971473	553	262	26.8	47.0	2.89	4.32	0.78	0.25	8.73	19.8	n.a.	3.50
38	4505180	5971501	493	234	39.9	45.8	4.47	n.a.	0.87	0.13	10.6	18.4	n.a.	4.28
39	4505146	5971531	399	149	23.3	27.9	2.42	4.86	0.88	< 0.01	9.36	21.4	0.97	3.82
40	4505107	5971561	421	185	43.8	37.0	4.51	5.19	0.84	0.13	10.3	19.5	n.a.	3.73
41	4505050	5971541	446	194	42.9	38.2	2.27	5.78	0.86	0.08	11.2	21.1	1.04	3.94
42	4505089	5971510	488	276	92.4	86.0	1.99	6.62	1.04	0.83	7.37	22.6	n.a.	5.33
43	4505125	5971482	518	309	96.5	117	6.13	6.90	0.96	2.15	10.4	16.3	1.01	3.59
44	4505162	5971452	421	174	30.3	35.8	3.09	5.21	0.82	1.72	9.45	21.1	n.a.	3.37
45	4505199	5971421	412	192	24.3	43.8	2.38	4.29	0.76	0.08	9.00	19.7	0.85	2.77
46	4505237	5971391	337	135	28.6	29.9	2.69	5.17	0.88	< 0.01	8.18	18.9	n.a.	3.08
47	4505274	5971362	359	158	28.2	31.1	3.19	5.23	0.91	0.17	10.7	17.6	0.98	3.05
48	4505312	5971332	509	285	28.0	33.8	2.99	5.09	1.05	0.25	11.1	21.9	n.a.	3.02
49	4505348	5971302	541	270	30.9	47.4	2.18	4.24	0.79	< 0.01	7.37	22.4	0.89	3.02
50	4505387	5971271	436	220	53.3	41.0	6.74	5.25	0.77	0.04	7.27	16.4	n.a.	4.46
51	4505424	5971239	477	235	59.9	47.0	6.21	5.49	0.83	0.25	7.00	16.2	n.a.	4.35
52	4505462	5971213	442	285	50.9	40.2	5.73	5.41	0.92	0.17	10.1	15.6	n.a.	4.46
53	4505498	5971181	485	235	50.5	39.4	4.61	5.56	0.87	0.08	11.9	20.7	1.56	3.55
54	4505468	5971136	539	224	103	78.8	4.53	5.94	0.98	0.21	12.7	23.7	n.a.	4.30
55	4505428	5971169	557	214	63.2	54.2	4.11	5.74	0.87	3.40	11.8	24.9	1.65	4.46
56	4505393	5971199	537	253	51.9	47.8	4.63	5.50	0.91	0.21	8.00	23.4	n.a.	4.88

Table A.2 continued

Sample	**Easting m**	**Northing m**	**AR-P mg kg^{-1}**	**WH-P mg kg^{-1}**	**AAC-P mg kg^{-1}**	**CAL mg kg^{-1}**	**CaCl$_2$-P mg kg^{-1}**	**pH**	**C$_{tot}$ %**	**CaCO$_3$ %**	**Clay %**	**Rb mg kg^{-1}**	**Fe g kg^{-1}**	**Zn mg kg^{-1}**
58	4505320	5971258	369	181	26.6	35.8	2.43	n.a	0.70	0.75	9.00	17.3	n.a.	3.28
59	4505282	5971289	390	168	25.9	33.4	1.75	4.34	0.72	0.29	11.4	18.9	n.a.	3.06
60	4505243	5971319	382	105	21.8	24.7	2.05	4.90	0.80	0.08	11.2	22.9	n.a.	2.96
61	4505206	5971352	338	128	20.9	22.3	1.54	5.41	0.62	< 0.01	12.8	22.5	n.a.	3.26
62	4505168	5971380	400	168	54.6	50.2	1.37	6.58	0.83	1.53	12.7	25.1	n.a.	4.16
63	4505127	5971407	450	127	26.6	32.7	2.54	4.82	0.81	1.82	11.5	24.8	n.a.	3.71
64	4505094	5971438	434	152	35.3	33.0	4.04	5.29	0.92	0.04	11.2	23.1	n.a.	4.48
65	4505056	5971471	486	190	35.9	34.0	3.23	5.33	0.86	0.09	10.8	22.5	n.a.	4.96
66	4505015	5971507	500	242	56.4	35.6	2.78	4.80	0.86	0.04	14.5	22.0	n.a.	4.23
67	4504979	5971538	465	231	50.2	51.8	0.75	6.88	0.81	0.13	15.0	28.0	n.a.	4.34
68	4504993	5971455	476	233	59.6	55.8	1.32	6.84	0.88	0.13	13.9	28.7	n.a.	4.50
69	4505029	5971425	524	319	43.1	72.3	1.18	7.18	1.17	4.62	11.4	26.7	n.a.	4.64
70	4505067	5971395	377	171	33.0	32.1	2.40	5.27	0.84	0.13	10.2	22.6	0.78	3.83
71	4505105	5971363	383	173	26.9	31.9	2.36	4.95	0.90	0.09	9.54	21.0	n.a.	3.93
72	4505141	5971333	399	162	33.5	39.8	1.56	4.24	0.71	< 0.01	9.27	19.3	1.56	3.08
73	4505180	5971303	399	171	38.5	43.0	1.80	4.25	0.72	0.85	8.54	20.0	n.a.	3.11
74	4505218	5971270	421	173	37.8	38.2	2.45	4.52	0.73	0.09	9.72	21.4	1.66	3.36
75	4505255	5971241	369	162	36.9	39.0	1.67	4.31	0.66	0.09	9.09	19.4	n.a.	3.54
76	4505292	5971214	482	213	52.5	50.7	2.64	4.29	0.64	0.13	9.18	19.3	1.64	3.77
77	4505330	5971184	433	224	47.9	44.9	4.76	5.17	0.81	0.09	10.4	19.2	n.a.	4.82
78	4505368	5971151	421	227	38.5	45.5	3.77	4.77	0.91	< 0.01	9.27	17.7	n.a.	4.03
79	4505404	5971121	400	193	30.6	36.1	2.69	4.82	0.80	0.13	13.4	16.6	2.10	3.36
80	4505378	5971074	465	269	68.8	63.3	4.14	5.59	0.87	< 0.01	9.27	17.5	n.a.	3.63
81	4505343	5971106	411	201	34.4	42.3	3.03	5.06	0.80	< 0.01	6.91	22.6	1.78	3.38
82	4505304	5971135	466	240	51.4	46.5	6.52	5.14	0.80	< 0.01	9.18	18.2	n.a.	4.61
83	4505266	5971166	431	185	34.1	39.0	3.95	5.03	0.73	0.08	7.55	18.0	1.99	3.39

Table A.2 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**CaCl$_2$-P** mg kg^{-1}	**pH**	**C$_{tot}$** %	**CaCO$_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
84	4505229	5971197	471	219	73.8	82.0	2.26	6.33	0.85	0.42	8.18	20.6	n.a.	4.28
85	4505192	5971226	385	187	71.7	69.6	2.22	6.49	0.92	0.26	7.55	21.3	n.a.	4.26
86	4505154	5971255	406	115	28.9	29.6	1.20	6.09	0.75	0.09	8.09	20.6	2.12	3.18
87	4505116	5971285	330	139	22.4	28.1	1.12	5.22	0.74	0.17	11.2	20.6	n.a.	3.21
88	4505078	5971316	359	191	54.0	52.0	3.02	5.88	0.90	< 0.01	8.45	20.7	2.02	3.88
89	4505041	5971346	425	304	45.4	81.5	1.22	6.51	1.48	4.81	8.36	25.3	n.a.	5.13
90	4505004	5971376	405	189	30.7	34.4	1.71	5.58	0.92	0.17	9.91	20.1	0.82	3.92
91	4504978	5971417	488	209	35.9	39.2	2.90	5.13	0.91	0.04	10.4	19.1	0.86	4.25
92	4504941	5971444	497	205	34.2	37.5	1.49	5.71	0.89	< 0.01	9.91	18.8	n.a.	4.02
93	4504897	5971463	478	131	18.4	26.0	0.51	4.61	1.05	< 0.01	9.91	21.3	0.83	4.49
94	4504853	5971432	416	117	33.1	34.0	0.21	6.32	1.09	0.17	10.0	21.0	n.a.	3.99
95	4504889	5971401	406	128	35.1	36.9	0.55	6.59	1.14	0.68	12.8	23.1	0.99	4.33
96	4504926	5971372	426	241	58.0	66.4	0.49	6.86	1.14	1.10	9.63	15.8	n.a.	4.93
98	4505003	5971314	456	215	63.8	66.4	1.19	6.89	1.09	0.42	8.82	20.7	1.02	4.73
99	4505039	5971281	487	260	51.0	71.1	0.79	7.06	1.33	0.61	10.4	23.7	n.a.	5.17
100	4505075	5971250	477	206	39.5	40.5	4.20	6.01	1.08	0.13	10.2	22.4	3.27	4.93
102	4505151	5971190	157	84.1	20.9	14.0	1.44	5.59	0.18	0.17	7.00	6.2	n.a.	1.13
103	4505187	5971158	477	221	37.4	42.6	4.64	5.07	0.85	0.08	10.0	18.7	0.97	3.82
104	4505228	5971130	436	229	62.5	49.9	5.76	5.55	0.93	0.36	11.8	18.1	n.a.	3.94
105	4505265	5971101	487	262	59.6	48.0	6.31	5.79	0.91	0.08	11.0	19.3	1.13	4.71
106	4505302	5971071	497	238	49.0	47.0	3.76	5.61	0.85	0.08	9.13	22.3	n.a.	4.13
107	4505340	5971043	548	335	74.8	69.6	5.92	5.49	0.90	0.17	8.77	20.3	0.94	3.93
108	4505282	5971013	558	347	134	124	5.46	6.02	0.83	0.08	8.41	17.9	n.a.	4.01
109	4505244	5971046	527	228	48.9	45.1	4.21	n.a.	0.88	0.13	9.14	22.4	1.01	4.00
110	4505207	5971077	517	280	89.6	105	2.46	6.83	0.98	0.93	11.0	22.6	n.a.	5.18
111	4505171	5971104	406	172	36.4	35.0	3.20	5.59	0.79	0.08	9.77	17.9	1.00	3.56

Table A.2 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**$CaCl_2$-P** mg kg^{-1}	**pH**	**C_{tot}** %	**$CaCO_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
112	4505134	5971136	446	197	29.1	41.7	1.98	6.65	0.96	0.47	8.32	18.1	n.a.	3.25
113	4505094	5971166	374	139	24.5	32.7	1.64	4.55	0.79	0.13	11.0	18.1	0.99	3.40
114	4505057	5971197	414	228	33.2	46.5	2.14	n.a.	0.67	< 0.01	11.1	14.3	n.a.	3.43
115	4504934	5971253	411	171	29.8	31.2	2.86	5.12	0.98	0.89	8.32	18.5	1.02	4.07
116	4504898	5971278	779	312	41.5	88.2	1.56	6.17	1.15	0.08	8.41	37.2	n.a.	5.15
118	4504872	5971346	395	111	40.0	23.9	1.03	5.80	0.90	0.13	6.14	20.6	n.a.	3.25
119	4504830	5971366	410	159	35.8	36.3	n.a.	6.02	0.88	0.04	8.68	18.2	1.15	4.07
121	4504757	5971439	506	258	153	82.6	0.88	6.30	0.81	0.13	9.96	21.8	0.97	4.17
122	4504719	5971465	504	234	44.2	43.0	2.32	6.03	0.86	0.08	8.50	19.4	n.a.	4.41
123	4504681	5971498	505	254	56.1	61.0	3.07	6.01	0.78	0.13	10.7	25.9	n.a.	4.51
124	4504640	5971529	589	329	56.2	56.2	2.82	5.58	0.90	0.04	9.23	22.0	n.a	5.62
125	4504600	5971562	557	308	86.3	88.2	5.12	6.18	0.92	1.83	13.1	21.9	1.03	5.59
126	4504574	5971585	558	284	92.9	90.6	3.96	6.31	0.90	0.13	10.8	21.5	n.a.	5.52
127	4504535	5971618	510	250	80.6	79.2	3.96	6.43	0.90	0.08	10.8	21.0	0.86	5.00
128	4504495	5971640	552	378	79.5	68.3	3.42	6.20	0.99	0.17	10.5	21.0	n.a.	5.38
129	4504456	5971675	489	268	39.7	40.8	3.48	5.44	0.78	0.13	10.2	17.2	1.12	4.58
130	4504365	5971687	632	400	154	81.6	3.54	6.38	0.83	0.21	10.2	16.5	n.a.	4.68
131	4504403	5971662	479	269	61.7	56.4	3.41	5.87	0.68	< 0.01	7.86	16.9	n.a.	3.49
132	4504429	5971640	504	285	57.3	56.6	3.39	5.55	0.84	< 0.01	7.41	20.1	0.96	4.24
133	4504469	5971607	489	251	47.1	43.4	4.70	n.a.	0.78	0.08	7.68	17.2	n.a.	4.32
134	4504513	5971565	468	197	29.0	38.2	2.25	4.85	0.72	0.04	9.68	19.3	0.90	3.61
135	4504552	5971535	478	203	29.0	35.1	2.31	4.87	0.71	2.47	7.86	19.7	n.a.	3.70
136	4504591	5971507	532	261	44.9	45.6	2.38	5.67	0.80	0.75	9.14	19.7	n.a.	4.45
137	4504629	5971475	563	299	72.7	66.6	3.04	5.97	0.81	1.40	9.41	23.2	n.a.	4.89
138	4504666	5971440	504	243	44.5	45.6	2.50	5.90	0.80	0.24	9.41	22.8	1.05	5.29
139	4504703	5971411	474	201	39.9	43.8	1.00	6.26	0.82	0.25	11.5	20.8	n.a.	4.18

Table A.2 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**$CaCl_2$-P** mg kg^{-1}	**pH**	**C_{tot}** %	**$CaCO_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
140	4504737	5971386	511	263	61.7	67.2	1.04	7.09	0.84	0.08	11.3	25.6	1.40	4.55
141	4504777	5971357	474	207	28.2	37.3	1.56	5.98	0.90	0.21	10.0	19.6	n.a.	3.54
142	4504814	5971326	447	154	21.4	29.3	1.32	5.50	0.82	1.22	13.0	17.8	0.81	3.27
143	4504851	5971296	658	427	228	128	n.a.	n.a.	0.76	0.84	9.32	20.9	n.a.	4.32
144	4504889	5971266	389	156	47.8	45.3	0.74	6.38	0.87	0.55	8.23	20.1	1.10	4.05
145	4504927	5971236	415	171	39.0	38.8	1.83	6.69	1.04	0.25	10.1	18.7	n.a.	5.10
146	4504972	5971213	416	180	51.9	58.8	0.80	6.74	0.99	0.63	9.68	20.2	1.15	5.45
147	4505004	5971176	431	251	38.8	64.9	0.80	6.92	1.30	3.55	8.77	22.8	n.a.	4.72
148	4505042	5971148	462	151	30.7	36.0	1.76	6.63	0.78	0.17	9.68	21.5	1.10	3.35
149	4505075	5971118	400	147	23.5	32.1	1.79	6.03	0.83	1.31	11.3	18.8	n.a.	3.20
151	4505156	5971048	505	270	83.9	75.3	4.69	6.19	0.87	0.17	8.86	19.1	0.84	4.61
152	4505190	5971024	504	228	72.5	58.8	3.36	6.22	0.95	0.08	9.05	19.3	n.a.	4.78
153	4505227	5970992	437	226	37.6	50.1	2.78	6.07	0.70	0.09	9.14	18.7	0.89	3.56
154	4505190	5970953	473	270	88.5	79.2	4.31	6.20	0.76	0.21	8.77	17.0	n.a.	3.92
155	4505153	5970985	474	244	65.4	56.2	4.79	6.00	1.08	0.17	7.77	18.2	n.a.	3.97
156	4505118	5971014	437	202	58.9	54.9	2.91	6.12	0.90	0.21	8.50	18.1	0.96	4.12
157	4505079	5971045	405	199	33.5	38.6	2.75	5.78	0.84	0.21	8.41	16.5	n.a.	3.98
158	4505042	5971073	347	131	24.4	26.5	0.85	5.72	0.77	0.21	7.41	17.5	0.84	2.78
159	4505002	5971104	353	139	26.4	25.4	1.70	4.13	0.88	0.17	8.05	19.4	n.a.	3.89
160	4504964	5971135	399	165	45.5	43.2	1.37	5.84	0.96	0.26	9.23	20.1	1.06	4.92
161	4504930	5971165	415	198	48.3	44.5	2.19	5.90	0.98	0.13	9.68	21.9	n.a.	5.34
162	4504897	5971195	458	215	32.1	71.6	0.49	6.52	0.99	0.98	10.8	26.9	0.01	5.29
163	4504857	5971229	389	178	47.1	42.3	2.59	6.15	0.82	< 0.01	13.8	18.4	n.a.	4.73
164	4504824	5971251	400	160	25.5	29.5	1.49	4.75	0.84	0.17	8.59	19.6	0.89	4.52
166	4504743	5971317	495	256	82.8	47.3	2.41	4.99	0.87	0.09	9.41	19.7	n.a.	4.87
167	4504705	5971348	473	243	69.4	56.4	4.23	5.55	0.86	0.35	8.41	18.1	0.88	4.99

Table A.2 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
168	4504668	5971380	499	247	73.6	68.3	4.31	5.74	0.92	0.42	9.59	20.0	n.a.	5.50
169	4504627	5971406	568	314	76.2	66.8	4.86	5.77	0.88	0.13	11.9	23.8	1.04	4.48
170	4504594	5971429	420	259	35.2	37.7	2.60	5.45	0.76	0.63	8.86	18.8	n.a.	2.91
171	4504555	5971462	483	255	52.7	46.6	4.52	5.22	0.80	< 0.01	9.59	20.0	0.88	2.61
172	4504522	5971484	495	223	45.6	43.6	4.63	n.a.	0.82	0.04	10.7	21.8	n.a.	n.a.
173	4504482	5971518	420	199	35.9	37.7	2.91	5.10	0.90	0.04	11.0	22.2	1.07	n.a.
174	4504443	5971551	416	204	44.2	39.3	2.49	5.30	0.69	0.97	9.32	19.6	n.a.	n.a.
175	4504403	5971585	554	324	56.8	89.8	1.21	6.47	1.09	3.08	12.4	24.7	1.54	n.a.
176	4504364	5971607	494	279	98.2	84.4	2.42	6.50	0.92	0.21	10.9	22.1	n.a.	n.a.
178	4504258	5971629	395	190	33.4	31.0	1.74	5.99	0.68	0.08	7.50	16.6	0.94	n.a.
179	4504298	5971607	447	250	42.7	54.9	0.59	6.54	1.10	1.27	11.1	22.6	n.a.	n.a.
180	4504337	5971573	479	316	63.7	71.8	1.12	6.90	0.90	1.53	8.50	18.2	1.20	n.a.
181	4504377	5971540	510	264	75.0	60.7	2.63	6.62	1.05	0.13	10.5	21.5	n.a.	n.a.
182	4504410	5971507	458	296	27.7	71.4	0.94	6.95	1.21	4.43	10.2	21.1	1.19	n.a.
183	4504451	5971481	410	171	36.1	39.0	2.77	5.97	0.83	0.89	10.4	21.3	n.a.	n.a.
184	4504487	5971453	410	178	34.3	37.3	3.46	5.32	0.84	0.89	9.50	19.8	0.95	n.a.
185	4504526	5971423	441	218	36.5	41.9	2.87	5.15	0.75	0.88	9.14	19.3	n.a.	n.a.
186	4504562	5971390	463	228	41.8	43.2	3.62	5.37	0.73	0.88	9.50	19.9	0.94	n.a.
187	4504600	5971360	488	217	42.6	43.2	3.83	5.30	0.72	1.44	9.77	20.3	n.a.	n.a.
188	4504634	5971329	489	238	46.3	44.7	3.69	5.21	0.76	0.13	9.77	20.3	0.89	n.a.
189	4504673	5971295	495	206	48.2	45.8	3.13	n.a.	0.78	0.04	9.41	19.7	n.a.	n.a.
190	4504719	5971262	446	213	51.0	64.9	0.67	6.25	0.99	1.27	13.1	25.8	1.59	n.a.
191	4504752	5971240	378	139	25.1	30.6	1.07	5.03	0.73	< 0.01	7.50	16.6	n.a.	n.a.
192	4504792	5971206	383	146	27.0	32.5	1.89	4.94	0.76	< 0.01	9.32	19.6	0.94	n.a.
193	4504826	5971183	447	211	37.4	53.8	0.76	6.34	0.97	2.06	13.8	26.9	n.a.	n.a.
194	4504861	5971153	302	177	35.8	39.9	3.10	5.79	0.87	0.08	10.0	20.8	0.99	n.a.

Table A.2 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
195	4504899	5971122	421	269	40.9	63.8	0.65	6.74	1.29	3.86	11.0	22.4	n.a.	n.a.
196	4504938	5971093	487	300	53.8	82.2	1.84	6.90	1.27	3.69	10.2	21.1	1.25	n.a.
197	4504976	5971061	434	259	64.4	79.8	2.00	6.93	1.10	0.50	9.50	19.8	n.a.	n.a.
198	4505012	5971030	434	210	41.3	39.0	3.04	n.a.	0.90	0.17	9.68	20.1	1.05	n.a.
199	4505049	5971001	401	194	45.3	41.2	3.87	5.56	0.69	3.41	7.23	16.2	n.a.	n.a.
200	4505087	5970971	487	304	111	81.6	3.63	6.24	0.81	< 0.01	9.14	19.3	n.a.	n.a.
201	4505126	5970945	507	345	106	79.2	3.90	5.97	1.07	0.25	8.86	18.8	0.87	n.a.
202	4505161	5970905	519	363	191	176	4.65	6.16	0.91	0.13	8.05	17.5	n.a.	n.a.

n.a. = not analysed/not available

Tab. A.3: Exchangeable cations and soil texture analysis on randomly selected samples from Kassow (E12º06’, N53º 10’).

Sample	**Easting**	**Northing**	**CEC**	**pH**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**Sand**	**Silt**	**Clay**
			$mmol_c$ $100g^{-1}$				**$mmol_c$ $100g^{-1}$**			**%**	**%**	**%**
8	4505391	5971472	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	68.5	25.1	6.37
22	4505421	5971379	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	67.2	25.4	7.34
27	4505605	5971231	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	74.0	20.3	5.63
83	4505266	5971166	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	64.4	23.5	12.1
115	4504934	5971253	3.85	4.63	1.18	2.11	32.0	3.21	<0.01	64.5	27.2	8.22
121	4505269	5971010	2.02	5.65	1.78	2.99	0.24	2.95	1.23	67.3	25.5	7.21
131	4505196	5971077	8.03	6.15	1.36	2.26	71.8	4.84	<0.01	60.3	27.4	12.4
134	4504513	5971565	7.76	5.66	1.38	2.53	68.0	5.60	<0.01	63.2	27.6	9.51
141	4505125	5971147	4.05	4.63	1.18	2.16	33.8	3.37	<0.01	65.1	27.2	7.76
156	4505013	5971255	9.80	5.84	1.34	2.53	69.0	5.77	1.93	63.1	27.7	9.18
160	4504964	5971135	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	62.9	27.6	9.51
161	4504976	5971290	2.82	7.36	1.09	0.62	25.9	0.50	<0.01	60.4	27.3	12.3
166	4504940	5971326	9.55	7.10	1.35	2.60	89.6	1.96	<0.01	63.7	27.8	8.50
167	4504940	5971326	8.97	6.95	1.35	3.02	82.6	2.67	<0.01	58.1	32.1	9.79
175	4504403	5971585	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	52.6	34.7	12.7
196	4504938	5971093	8.38	5.94	1.34	2.28	74.0	6.18	<0.01	61.0	28.8	10.3

n.a. = not analysed/not available

Tab. A.4: Exchangeable cations and soil texture analysis on randomly selected samples from Warberg (E10º54’, N52º 10’).

Sample	Easting	Northing	CEC	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Sand	Silt	Clay
			mmol$_c$ 100g^{-1}			mmol$_c$ 100g^{-1}			%	%	%
GB_49	105343	521103	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.75	76.3	22.0
GB_54	105351	521103	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.55	84.4	14.1
GB_101	105356	521059	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.66	82.6	15.7
M2_55	105360	521058	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.13	79.7	18.2
M2_126	105402	521112	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.98	75.6	21.5
M2_102	105403	521106	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.32	84.4	14.3
M2_117	105405	521103	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.29	82.9	15.8
5a	105406	521113	20.2	6.94	0.45	1.27	18.4	0.09	7.00	71.0	22.0
M1_48	105407	521103	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.91	81.7	17.4
5b	105407	521113	20.6	7.15	0.66	1.00	18.8	0.09	7.00	69.0	24.0
M1_41	105408	521105	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.90	82.9	16.3
4a	105410	521103	34.0	7.23	0.47	1.53	21.5	3.24	4.00	63.0	33.0
BB_17	105410	521053	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.86	48.1	48.2
bb_11	105410	521054	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.70	58.1	39.3
BB_25	105410	521052	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.77	49.2	48.1
BB_12	105412	521054	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.44	61.8	35.7
3a	105413	521058	19.8	7.66	0.24	0.71	18.8	0.03	8.00	63.0	29.0
3b	105414	521055	29.4	7.64	0.43	1.39	27.5	0.05	11.00	61.0	28.0
2b	105416	521056	21.9	7.67	0.50	1.01	20.3	0.07	4.00	69.0	27.0
2a	105416	521054	22.22	7.63	0.48	1.13	20.6	0.06	4.00	72.0	24.0
BB_22	105418	521053	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.89	87.3	10.8
1a	105418	521057	22.8	7.54	0.49	1.19	20.4	0.69	7.00	69.0	24.0
1b	105426	521056	27.9	7.61	0.70	1.58	25.5	0.09	11.00	65.0	24.0
4b	105490	521103	43.4	7.28	0.89	2.67	34.8	5.06	4.00	61.0	35.0

Tab. A.5: Results of chemical soil analysis for grid samples from Warberg (E10º54’, N52º 10’).

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**CaCl$_2$-P** mg kg^{-1}	**pH**	**C$_{tot}$** %	**CaCO$_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
BB 1	4425145	5783794	542	378	168	125	1.47	7.55	1.24	1.52	16.1	35.4	1.18	61.2
BB 2	4425115	5783762	476	275	149	144	1.34	7.53	1.37	0.89	17.9	38.0	1.18	62.1
BB 3	4425145	5783762	827	581	38.4	52.4	0.46	7.71	1.83	6.17	28.9	53.5	1.70	154
BB 4	4425115	5783734	768	591	57.0	64.8	0.40	7.60	1.55	3.63	30.4	55.6	1.81	146
BB 5	4425146	5783734	269	98.3	52.7	37	0.28	7.59	0.79	0.43	16.0	35.3	1.22	45.4
BB 6	4425174	5783733	356	240	150	117	1.67	7.56	1.04	0.68	12.0	29.7	1.02	41.7
BB 7	4425085	5783705	680	578	133	96.7	0.60	7.64	1.40	2.16	30.9	56.4	1.93	90.8
BB 8	4425115	5783704	683	367	108	53.5	0.41	7.52	1.13	1.67	24.9	47.9	1.58	94.1
BB 9	4425145	5783702	346	171	102	73.0	0.56	7.54	0.97	0.47	11.8	29.5	1.01	48.2
BB 10	4425174	5783704	376	210	120	111	1.47	7.32	0.99	0.94	10.3	27.3	0.86	40.7
BB 11	4425055	5783672	554	364	119	77.1	0.61	7.56	1.67	2.15	31.6	57.3	2.00	57.7
BB 12	4425085	5783673	543	445	167	68.9	0.48	7.71	1.16	1.27	28.9	53.6	1.99	62.2
BB 13	4425115	5783673	263	149	90.3	64.8	0.63	7.42	0.90	0.21	17.7	37.7	1.32	59.1
BB 14	4425145	5783672	339	168	107	76.1	0.99	7.50	1.00	0.47	12.2	30.0	1.06	57.8
BB 15	4425175	5783672	393	183	108	93.6	1.06	7.63	1.09	0.85	12.7	30.7	1.07	46.8
BB 16	4425024	5783644	928	869	169	185	3.56	7.41	3.65	8.88	16.8	36.5	1.53	64.0
BB 17	4425054	5783645	875	640	88.2	103	1.08	7.50	2.10	5.10	51.3	85.1	2.33	64.7
BB 18	4425084	5783642	537	208	115	79.2	0.61	7.37	1.24	0.41	35.8	63.2	1.88	66.6
BB 19	4425114	5783643	448	183	106	73.0	0.75	7.36	1.14	0.21	20.5	41.7	1.23	71.4
BB 20	4425144	5783643	389	165	99.2	82.3	0.89	7.53	0.97	0.42	17.9	38.1	1.24	58.7
BB 21	4425174	5783644	465	177	107	90.5	0.96	7.44	0.97	0.30	15.9	35.2	1.28	52.3
BB 22	4425205	5783644	443	223	135	109	1.46	7.40	1.04	0.38	10.6	27.7	0.92	49.0
BB 23	4424993	5783613	829	614	153	171	2.88	7.45	3.36	8.87	12.6	30.6	1.24	67.5
BB 24	4425025	5783613	857	617	147	158	2.65	7.43	2.55	5.71	23.6	46.0	1.55	64.0
BB 25	4425055	5783612	965	627	122	128	1.42	7.44	1.87	2.55	53.8	88.7	2.35	65.0

Table A.5 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**$CaCl_2$-P** mg kg^{-1}	**pH**	**C_{tot}** %	**$CaCO_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
BB 26	4425085	5783614	558	199	107	86.4	1.08	7.39	1.41	0.21	30.6	56.0	1.61	72.8
BB 27	4425115	5783614	475	188	97.4	69.9	0.66	7.25	1.22	0.12	21.5	43.2	1.34	75.6
BB 28	4425145	5783614	431	169	113	101	1.13	7.33	0.95	0.21	15.7	34.9	1.12	58.4
BB 29	4425174	5783615	408	151	94.5	76.1	0.76	7.37	1.08	0.34	12.5	30.4	0.98	51.8
BB 30	4425204	5783614	417	182	120	107	0.94	7.51	1.07	1.27	12.9	31.0	1.30	48.4
BB 31	4424967	5783580	788	401	87.8	109	1.11	7.40	3.46	8.19	13.1	31.3	1.59	74.6
BB 32	4424995	5783582	728	n.a.	73.8	90.5	0.70	7.33	3.82	9.78	9.42	26.1	1.56	73.5
BB 33	4425024	5783584	672	400	148	148	2.00	7.17	2.18	2.52	23.9	46.4	2.09	63.7
BB 34	4425054	5783584	555	267	154	117	2.52	6.91	1.48	0.34	27.7	51.9	1.97	62.2
BB 35	4425085	5783583	489	408	117	76.1	1.06	6.93	1.50	0.34	30.8	56.2	1.92	67.7
BB 36	4425114	5783584	823	245	229	156	1.46	7.35	1.51	0.88	23.2	45.6	2.26	116
BB 37	4424965	5783554	676	375	74.3	92.5	0.71	7.32	2.68	6.32	26.7	50.5	1.93	63.7
GB 1	4424753	5784215	534	322	165	n.a.	1.82	7.50	n.a.	3.45	17.7	37.8	1.46	64.7
GB 2	4424695	5784183	545	327	109	n.a.	1.31	7.54	n.a.	8.87	17.2	37.1	1.31	84.9
GB 3	4424724	5784184	669	274	123	n.a.	0.48	7.57	n.a.	11.0	29.6	54.5	2.15	255
GB 4	4424755	5784184	469	244	175	n.a.	0.99	7.22	n.a.	0.29	20.1	41.1	1.64	56.7
GB 5	4424663	5784154	434	255	135	n.a.	1.05	7.44	n.a.	1.90	17.2	37.0	1.50	58.5
GB 6	4424695	5784153	317	204	118	78.6	0.99	7.41	n.a.	1.84	16.7	36.3	1.65	85.3
GB 7	4424725	5784152	306	122	75.0	n.a.	0.08	7.22	n.a.	0.78	18.4	38.8	1.59	49.3
GB 8	4424755	5784154	393	248	160	n.a.	0.99	7.21	n.a.	0.41	16.5	36.0	1.61	50.9
GB 9	4424604	5784123	388	240	150	n.a.	0.19	7.32	1.04	8.55	24.9	48.0	1.93	86.9
GB 10	4424634	5784123	534	160	94.6	n.a.	0.11	7.25	0.97	0.42	26.5	50.1	1.92	59.5
GB 11	4424665	5784124	299	146	61.6	n.a.	0.30	6.79	0.85	0.42	20.8	42.2	1.91	50.3
GB 12	4424695	5784123	283	133	70.0	n.a.	0.37	6.75	1.00	0.34	19.9	40.8	1.80	48.7
GB 13	4424725	5784124	464	165	96.0	n.a.	1.17	6.82	1.17	0.21	16.3	35.8	1.43	103

Table A.5 continued

Sample	Easting m	Northing m	AR-P mg kg^{-1}	WH-P mg kg^{-1}	AAC-P mg kg^{-1}	CAL mg kg^{-1}	$\mathrm{CaCl_2}$-P mg kg^{-1}	pH	C_{tot} %	$\mathrm{CaCO_3}$ %	Clay %	Rb mg kg^{-1}	Fe g kg^{-1}	Zn mg kg^{-1}
GB 14	4424754	5784124	519	221	145	n.a.	1.44	7.16	0.97	0.38	15.3	34.4	1.36	48.8
GB 15	4424575	5784093	477	154	91.0	n.a.	0.19	7.37	1.12	0.34	24.1	46.7	1.88	65.2
GB 16	4424605	5784094	428	129	80.5	n.a.	0.11	7.10	0.99	0.30	21.1	42.5	1.99	76.4
GB 17	4424635	5784093	504	178	97.7	n.a.	0.40	6.93	1.05	0.33	24.2	47.0	1.87	65.7
GB 18	4424664	5784093	659	304	127	n.a.	1.01	7.38	1.47	1.88	-9.1	n.a.	1.62	71.6
GB 19	4424695	5784093	583	210	114	n.a.	0.66	6.88	1.20	0.25	23.4	45.8	1.76	75.7
GB 20	4424724	5784093	364	97.1	51.2	n.a.	0.10	6.43	0.90	0.26	22.9	45.1	1.80	57.8
GB 21	4424755	5784094	390	178	125	n.a.	0.99	6.90	0.91	0.34	19.5	40.4	1.60	48.3
GB 22	4424543	5784064	757	288	93.9	n.a.	0.99	7.41	2.76	5.45	18.0	38.2	1.38	65.2
GB 23	4424575	5784064	460	124	64.6	n.a.	0.11	7.08	1.05	0.29	20.2	41.3	1.72	104
GB 24	4424605	5784063	411	117	62.1	42.6.	0.18	6.62	1.06	0.29	19.4	40.1	1.69	57.4
GB 25	4424636	5784064	456	171	99.4	n.a.	0.54	6.47	1.09	0.21	15.5	34.7	1.47	59.2
GB 26	4424665	5784064	541	266	144	n.a.	0.51	7.27	1.09	1.32	21.5	43.0	1.71	86.6
GB 27	4424695	5784063	628	280	145	n.a.	0.38	7.22	1.37	0.25	30.1	55.2	1.95	76.9
GB 28	4424725	5784063	426	144	78.0	n.a.	0.10	6.65	0.90	0.51	26.8	50.5	1.91	62.0
GB 29	4424755	5784063	493	210	116	n.a.	0.58	6.90	1.05	0.26	22.6	44.6	1.77	70.8
GB 30	4424545	5784034	552	201	79.7	n.a.	0.27	n.a.	1.74	4.17	20.1	41.1	1.73	58.4
GB 31	4424574	5784034	363	87.7	43.2	n.a.	0.08	7.49	1.04	0.38	19.9	40.9	1.73	54.3
GB 32	4424605	5784034	436	117	60.8	n.a.	0.16	6.91	1.13	0.17	17.1	36.9	1.53	57.6
GB 33	4424635	5784033	396	122	68.3	n.a.	0.42	6.60	0.98	0.21	14.8	33.6	1.42	79.4
GB 34	4424664	5784034	508	167	96.4	n.a.	0.29	7.04	1.01	0.21	17.4	37.3	1.49	54.1
GB 35	4424695	5784033	576	192	129	n.a.	0.77	7.17	1.13	0.26	21.2	42.7	1.58	91.2
GB 36	4424724	5784034	727	305	138	n.a.	0.24	7.52	1.17	0.76	28.6	53.1	2.14	109
GB 37	4424755	5784033	754	312	179	n.a.	1.21	7.54	1.23	0.87	26.5	50.2	1.86	101
GB 38	4424784	5784033	726	362	173	n.a.	1.18	7.52	1.20	1.26	22.4	44.4	1.85	73.7
GB 39	4424545	5784004	474	181	88.9	n.a.	0.21	7.45	1.33	1.58	18.2	38.5	1.66	59.0

Table A.5 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
GB 40	4424574	5784003	376	125	66.2	n.a.	0.27	6.66	1.00	3.01	11.9	29.6	1.34	48.1
GB 41	4424605	5784004	356	91.0	51.2	n.a.	0.18	6.73	1.04	0.17	16.8	36.4	1.31	46.9
GB 42	4424635	5784003	413	104	62.1	n.a.	0.06	6.79	0.97	0.08	23.2	45.5	1.62	53.4
GB 43	4424665	5784003	482	162	95.2	n.a.	0.08	6.93	0.90	0.17	20.7	42.0	1.65	71.5
GB 44	4424695	5784004	491	168	95.2	n.a.	0.61	6.61	0.97	0.21	14.4	33.1	1.26	48.5
GB 45	4424724	5784004	505	149	83.9	n.a.	0.40	6.89	0.93	2.19	18.6	39.0	1.46	57.9
GB 46	4424755	5784004	570	245	157	n.a.	1.63	7.41	1.00	1.43	14.3	33.0	1.39	83.1
GB 47	4424785	5784004	577	262	166	n.a.	1.09	7.57	1.16	1.11	20.3	41.5	1.59	53.6
GB 48	4424514	5783974	1034	566	117	n.a.	0.77	7.43	1.82	2.50	28.1	52.4	1.80	89.7
GB 49	4424545	5783973	580	204	110	n.a.	0.14	7.37	1.09	0.64	26.8	50.5	1.86	71.9
GB 50	4424575	5783973	460	144	77.6	n.a.	0.77	6.63	1.01	0.30	13.7	32.1	1.28	55.9
GB 51	4424604	5783974	443	138	78.8	n.a.	0.67	6.53	1.00	0.54	15.3	34.3	1.32	51.8
GB 52	4424634	5783973	401	131	70.4	n.a.	0.13	6.62	0.96	0.26	17.2	37.1	1.44	45.9
GB 53	4424665	5783974	467	150	83.0	n.a.	0.03	6.50	0.95	0.17	15.1	34.1	1.32	86.8
GB 54	4424695	5783973	470	195	104	59.8	1.02	6.55	0.93	0.30	14.9	33.8	1.25	46.7
GB 55	4424725	5783973	442	157	80.1	n.a.	1.31	6.13	0.95	0.17	12.1	29.8	1.27	47.4
GB 56	4424755	5783973	477	167	105	n.a.	0.18	7.21	0.91	0.43	17.3	37.2	1.74	48.0
GB 57	4424785	5783974	514	242	160	n.a.	1.57	7.32	1.05	0.46	14.2	32.9	1.80	49.4
GB 58	4424514	5783943	1150	749	67.1	n.a.	0.37	7.49	2.74	0.85	27.1	51.0	1.23	103
GB 59	4424545	5783943	572	202	106	n.a.	0.11	7.28	1.05	1.27	22.6	44.7	1.84	70.0
GB 60	4424575	5783943	409	127	60.8	n.a.	0.46	6.52	1.02	0.21	14.2	32.9	1.37	46.1
GB 61	4424604	5783944	392	118	58.7	n.a.	0.26	6.35	0.98	0.34	13.4	31.7	1.30	52.1
GB 62	4424634	5783944	374	131	71.3	n.a.	0.40	6.71	0.99	0.21	14.8	33.6	1.39	51.6
GB 63	4424665	5783944	372	137	80.5	n.a.	0.46	6.66	0.93	0.12	13.9	32.4	1.31	165
GB 64	4424695	5783944	477	194	122	n.a.	1.74	6.52	0.99	0.25	12.3	30.2	1.21	64.4
GB 65	4424725	5783943	411	123	64.6	n.a.	0.90	6.16	0.90	0.17	14.3	33.0	1.37	44.2

Table A.5 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**CaCl$_2$-P** mg kg^{-1}	**pH**	**C$_{tot}$** %	**CaCO$_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
GB 66	4424755	5783944	428	180	126	n.a.	1.21	7.00	0.91	0.25	10.7	27.9	1.20	42.4
GB 67	4424784	5783943	466	218	151	n.a.	0.99	7.26	0.96	0.21	14.3	33.0	1.28	45.0
GB 78	4424784	5783913	498	225	65.4	n.a.	1.39	7.10	0.88	0.21	13.7	32.1	1.43	61.9
GB 79	4424455	5783883	576	218	155	n.a.	0.32	7.35	1.19	0.79	25.3	48.5	1.79	49.4
GB 80	4424485	5783883	382	115	74.2	n.a.	0.11	6.99	1.02	0.21	15.9	35.2	1.41	47.9
GB 81	4424514	5783883	897	584	138	n.a.	0.29	7.35	1.38	1.67	31.6	57.4	2.20	120
GB 82	4424545	5783883	456	173	106	99.0	0.74	6.88	1.07	0.42	16.6	36.2	1.37	137
GB 83	4424575	5783883	342	162	88.1	n.a.	0.88	6.55	1.03	3.47	14.2	32.9	1.17	44.0
GB 84	4424605	5783884	436	128	62.1	n.a.	0.67	6.19	0.94	0.04	14.4	33.1	1.35	58.0
GB 85	4424635	5783883	415	111	54.1	n.a.	0.29	6.36	0.97	0.08	15.3	34.3	1.33	50.9
GB 86	4424665	5783883	433	190	106	n.a.	1.04	6.64	1.00	0.08	15.6	34.8	1.39	47.5
GB 87	4424695	5783883	499	185	113	n.a.	1.23	6.66	1.03	0.04	14.1	32.8	1.29	48.1
GB 88	4424724	5783883	515	203	112	n.a.	1.05	6.84	1.01	0.17	16.6	36.2	1.23	55.6
GB 89	4424755	5783883	573	189	101	n.a.	0.08	6.58	0.86	0.12	26.2	49.8	1.42	102
GB 90	4424785	5783884	533	221	132	45.4	1.34	6.83	0.96	0.16	15.6	34.8	2.08	48.4
GB 91	4424484	5783854	519	196	135	n.a.	0.75	7.03	1.00	< 0.01	18.4	38.8	1.61	46.7
GB 92	4424514	5783853	719	370	193	n.a.	0.69	7.24	1.37	0.62	23.9	46.5	1.42	60.4
GB 93	4424545	5783852	343	124	73.8	n.a.	0.11	6.84	0.98	0.17	19.9	40.9	1.67	43.7
GB 94	4424574	5783853	475	144	103	n.a.	0.83	6.73	1.03	0.08	15.4	34.5	1.61	46.9
GB 95	4424605	5783854	433	127	86.4	n.a.	0.56	6.44	1.03	0.04	13.3	31.5	1.37	44.1
GB 96	4424634	5783854	409	101	59.1	n.a.	0.13	6.30	0.97	0.08	18.3	38.6	1.29	45.0
GB 97	4424665	5783854	499	120	69.2	n.a.	0.14	6.73	0.99	0.13	22.2	44.2	1.36	58.2
GB 98	4424695	5783853	494	167	96.9	n.a.	0.35	6.97	0.93	0.08	21.6	43.3	1.68	59.1
GB 99	4424724	5783853	420	134	94.8	n.a.	0.70	6.62	0.93	0.17	18.8	39.2	1.68	46.0
GB 100	4424752	5783854	527	131	88.9	n.a.	0.18	6.54	0.84	0.17	22.4	44.4	1.44	62.9
GB 101	4424785	5783854	504	181	120	n.a.	1.13	6.94	0.90	0.08	17.8	37.9	1.70	51.1

Table A.5 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**$CaCl_2$-P** mg kg^{-1}	**pH**	**C_{tot}** %	**$CaCO_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
GB 102	4424815	5783853	430	209	148	n.a.	1.97	7.09	0.94	0.29	11.9	29.6	1.52	44.5
GB 103	4424514	5783824	711	338	192	n.a.	0.56	7.38	1.22	1.45	27.8	52.0	1.09	57.3
GB 104	4424545	5783825	458	166	117	n.a.	0.13	7.16	1.12	1.09	22.0	43.8	1.95	48.3
GB 105	4424574	5783824	385	125	84.3	n.a.	0.08	7.11	0.98	0.29	18.2	38.5	1.65	43.8
GB 106	4424603	5783824	370	115	71.3	n.a.	0.38	6.40	1.07	0.21	17.5	37.5	1.40	44.2
GB 107	4424634	5783823	381	119	77.6	n.a.	0.59	6.55	1.14	0.21	14.7	33.5	1.26	46.6
GB 108	4424665	5783822	419	112	51.6	n.a.	0.35	6.53	1.12	0.08	24.3	47.1	1.25	59.3
GB 109	4424694	5783824	373	119	78.4	56.1	0.30	6.73	1.06	0.21	22.6	44.7	2.05	55.7
GB 110	4424724	5783823	406	180	134	n.a.	0.84	6.93	0.96	0.21	19.4	40.1	1.66	51.7
GB 111	4424755	5783823	379	112	62.9	n.a.	0.77	5.93	0.99	0.21	17.2	37.0	1.46	47.6
GB 112	4424783	5783825	471	121	84.3	n.a.	0.17	6.82	0.89	0.13	18.6	39.0	1.38	53.9
GB 113	4424814	5783823	401	136	93.1	n.a.	0.65	6.89	0.93	0.76	15.1	34.1	1.45	42.3
GB 114	4424545	5783793	617	290	201	n.a.	0.48	7.27	1.17	0.17	21.0	42.4	1.32	47.1
GB 115	4424574	5783793	437	140	98.5	n.a.	0.06	7.09	1.05	9.10	20.3	41.5	1.59	47.5
GB 116	4424605	5783794	500	140	98.1	36.0	0.14	7.03	1.10	0.13	19.2	39.8	1.49	51.8
GB 117	4424634	5783793	408	105	74.2	n.a.	0.02	7.64	0.97	0.13	20.7	41.9	1.41	50.4
GB 118	4424665	5783793	522	153	95.6	n.a.	0.02	7.18	1.14	0.21	24.1	46.7	1.69	56.5
GB 119	4424695	5783793	538	176	119	n.a.	0.32	6.86	1.08	0.12	21.9	43.7	1.61	62.0
GB 120	4424725	5783795	508	181	140	n.a.	0.93	6.61	1.04	0.08	16.6	36.2	1.52	56.3
GB 121	4424754	5783796	420	116	76	n.a.	0.38	6.41	1.00	0.30	18.6	39.0	1.38	49.8
GB 122	4424785	5783793	418	111	77.6	n.a.	0.30	6.72	0.83	0.17	16.8	36.6	1.48	47.5
GB 123	4424815	5783792	444	198	150	n.a.	0.84	7.19	0.88	0.88	17.9	38.0	1.54	49.8
GB 124	4424575	5783765	452	142	98.5	n.a.	0.03	7.21	0.91	0.29	18.6	39.0	1.62	48.4
GB 125	4424605	5783763	363	97.2	76.7	n.a.	0.17	7.09	1.15	0.21	16.1	35.4	1.38	45.1
GB 126	4424635	5783765	309	119	93.5	n.a.	0.15	6.83	1.08	0.17	18.1	38.3	1.45	37.6
GB 127	4424665	5783763	365	98.2	73.8	n.a.	0.09	6.70	0.89	0.08	14.5	33.3	1.43	44.1

Table A.5 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
GB 128	4424695	5783764	456	198	156	n.a.	0.26	7.30	1.22	0.51	16.7	36.3	1.43	55.5
GB 129	4424725	5783763	509	240	140	n.a.	0.42	6.77	0.96	0.12	28.7	53.2	1.90	50.0
GB 130	4424754	5783763	284	218	151	n.a.	0.59	6.99	1.00	0.21	16.8	36.6	1.39	45.4
GB 131	4424785	5783763	451	126	91.4	n.a.	0.05	6.52	0.81	0.17	19.4	40.1	1.44	51.4
GB 132	4424815	5783764	547	208	156	n.a.	1.25	7.27	1.02	0.42	18.5	38.9	1.60	47.9
GB 133	4424604	5783735	514	153	101	n.a.	0.05	7.06	1.17	0.34	19.7	40.6	1.45	46.2
GB 134	4424634	5783734	414	115	88.5	n.a.	0.09	6.90	1.19	0.08	13.8	32.3	1.65	40.9
GB 135	4424665	5783734	402	126	88.1	n.a.	0.14	6.58	1.01	2.18	14.9	33.9	1.30	41.7
GB 136	4424695	5783734	410	191	141	n.a.	0.06	7.13	2.00	0.33	23.0	45.2	1.36	48.6
GB 137	4424725	5783734	547	186	n.a.	n.a.	0.20	7.01	1.03	0.29	19.9	40.9	1.73	48.8
GB 138	4424754	5783734	559	183	115	n.a.	0.95	6.36	1.24	0.21	15.0	34.0	1.57	49.2
GB 139	4424784	5783732	442	114	67.1	n.a.	0.18	6.36	1.01	0.17	20.8	42.2	1.27	55.0
GB 140	4424814	5783734	534	200	149	n.a.	0.99	7.01	0.99	0.12	17.9	38.0	1.61	49.6
GB 141	4424634	5783701	511	198	162	n.a.	0.26	6.70	0.97	0.21	15.2	34.2	1.68	46.0
GB 142	4424665	5783703	450	139	103	n.a.	0.18	6.67	1.05	0.13	14.5	33.3	1.51	42.5
GB 143	4424695	5783704	494	141	92.2	n.a.	0.03	6.83	1.05	0.13	22.5	44.5	1.43	47.3
GB 144	4424725	5783703	475	129	92.7	n.a.	0.11	6.59	1.00	0.17	16.8	36.4	1.75	43.6
GB 145	4424755	5783702	492	168	127	n.a.	1.02	6.46	1.06	0.17	11.9	29.6	1.33	46.1
GB 146	4424785	5783704	534	129	88.1	n.a.	0.08	6.71	0.94	0.21	23.9	46.5	1.23	52.3
GB 147	4424814	5783703	516	158	122	n.a.	0.72	6.80	1.02	0.08	16.3	35.8	1.58	56.4
GB 148	4424664	5783673	679	289	193	n.a.	0.92	6.61	1.14	0.25	12.5	30.5	1.43	53.5
GB 149	4424695	5783673	499	164	113	n.a.	0.38	7.01	1.08	0.17	14.4	33.1	1.28	47.1
GB 150	4424725	5783675	602	175	117	n.a.	0.45	7.10	1.02	0.29	17.7	37.7	1.28	53.4
GB 151	4424756	5783672	491	174	130	n.a.	0.78	6.87	1.04	0.08	14.2	32.8	1.29	46.2
GB 152	4424784	5783673	394	98.2	73.0	n.a.	0.08	6.98	0.89	0.17	18.6	39.0	1.62	46.5
GB 153	4424814	5783674	296	105	78.8	n.a.	0.18	6.97	0.95	0.21	14.6	33.4	1.26	45.6

Table A.5 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**CaCl$_2$-P** **mg kg^{-1}**	**pH**	**C$_{tot}$** **%**	**CaCO$_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
GB 154	4424844	5783675	454	161	130	n.a.	0.93	7.32	0.99	0.26	12.0	29.7	1.28	43.8
GB 155	4424696	5783645	509	302	188	n.a.	2.03	6.66	1.06	0.17	10.8	28.0	1.24	41.9
GB 156	4424724	5783643	390	193	119	n.a.	0.23	7.37	1.04	0.21	22.5	44.5	1.69	50.4
GB 157	4424755	5783645	366	183	138	n.a.	0.45	7.21	1.03	0.26	21.8	43.5	1.60	50.0
GB 158	4424785	5783643	411	149	93.5	n.a.	1.02	6.62	0.99	0.09	12.4	30.3	1.25	50.3
GB 159	4424813	5783642	371	106	63.7	n.a.	0.33	6.56	0.88	0.13	15.0	33.9	1.48	43.8
GB 160	4424844	5783643	509	191	148	n.a.	0.95	7.43	0.96	0.51	14.6	33.4	1.28	48.8
GB 161	4424725	5783613	405	301	212	n.a.	1.81	7.32	1.17	0.17	13.2	31.4	1.21	42.1
GB 162	4424755	5783611	231	177	129	n.a.	0.15	7.20	1.01	0.08	17.5	37.4	1.43	45.9
GB 163	4424785	5783613	369	171	115	n.a.	1.08	6.68	1.03	0.17	13.3	31.6	1.19	46.4
GB 164	4424815	5783614	282	81.5	47.0	n.a.	0.11	6.14	0.83	0.13	12.2	30.0	1.31	40.3
GB 165	4424844	5783613	444	248	169	n.a.	0.92	7.40	1.00	0.30	16.5	36.0	1.48	47.2
GB 166	4424754	5783583	572	268	143	n.a.	0.14	7.56	1.08	0.21	20.5	41.6	1.61	53.9
GB 167	4424785	5783584	575	264	177	n.a.	0.78	7.17	1.21	0.25	15.8	35.1	1.35	54.1
GB 168	4424815	5783585	409	155	97.3	n.a.	0.03	7.38	1.04	0.09	22.2	44.2	1.78	54.1
GB 201	4424791	5784089	496	202	134	n.a.	0.81	7.45	1.07	0.34	15.3	34.4	1.47	59.9
GB 202	4424832	5783942	488	239	171	n.a.	0.87	7.51	1.07	0.30	14.9	33.8	1.52	56.6
GB 203	4424917	5783824	449	207	142	n.a.	0.99	n.a.	1.00	0.42	10.4	27.4	1.19	40.4
M1 1	4424934	5784273	298	87.2	46.2	29.1	0.28	6.22	0.89	n.a.	19.5	40.3	1.93	44.6
M1 2	4424965	5784274	250	106	n.a.	n.a.	0.36	6.17	0.84	n.a.	17.8	37.9	1.74	42.0
M1 3	4424994	5784274	282	250	91.8	n.a.	0.60	6.24	0.90	n.a.	15.3	34.4	1.46	42.1
M1 4	4425025	5784274	513	190	175	n.a.	0.46	7.27	1.10	n.a.	10.2	27.2	1.29	43.4
M1 5	4425052	5784274	325	237	125	n.a.	0.49	7.46	1.13	n.a.	9.2	25.8	1.39	39.1
M1 6	4424934	5784244	345	91.7	43.4	n.a.	0.08	6.34	0.92	n.a.	30.4	55.7	2.59	84.5
M1 7	4424965	5784244	338	109	57.6	n.a.	0.28	6.18	0.86	n.a.	20.5	41.7	1.86	48.0
M1 8	4424995	5784244	394	198	135	n.a.	0.33	7.15	1.01	n.a.	22.7	44.8	2.04	53.9

Table A.5 continued

Sample	Easting m	Northing m	AR-P mg kg^{-1}	WH-P mg kg^{-1}	AAC-P mg kg^{-1}	CAL mg kg^{-1}	CaCl$_2$-P mg kg^{-1}	pH	C$_{tot}$ %	CaCO$_3$ %	Clay %	Rb mg kg^{-1}	Fe g kg^{-1}	Zn mg kg^{-1}
M1 9	4425024	5784244	378	240	133	n.a.	0.39	7.33	0.92	n.a.	16.2	35.6	1.78	46.9
M1 10	4425054	5784243	346	175	113	n.a.	0.28	7.44	1.17	n.a.	8.5	24.8	1.32	38.6
M1 11	4424934	5784213	255	91.7	55.1	n.a.	0.41	6.52	0.95	n.a.	16.6	36.2	1.54	42.2
M1 12	4424965	5784214	346	129	80.1	n.a.	0.35	6.92	0.91	n.a.	16.7	36.4	1.59	92.6
M1 13	4424995	5784213	429	228	117	73.7	0.35	7.54	1.20	n.a.	16.2	35.6	1.64	51.6
M1 14	4425023	5784213	524	247	56.0	n.a.	0.25	7.66	2.11	n.a.	14.4	33.2	1.46	51.9
M1 15	4425054	5784213	576	281	90.5	n.a.	0.32	7.62	1.82	n.a.	15.9	35.2	1.47	55.7
M1 16	4424965	5784183	333	124	65.5	n.a.	0.16	7.37	0.99	n.a.	16.6	36.2	1.47	41.0
M1 17	4424994	5784183	385	191	81.3	n.a.	0.24	7.56	1.30	n.a.	12.8	30.9	1.48	43.4
M1 18	4425025	5784185	284	222	69.3	n.a.	0.24	7.63	1.47	n.a.	15.3	34.3	1.54	42.1
M1 19	4425055	5784183	234	202	111	n.a.	0.41	7.56	1.23	n.a.	14.4	33.1	1.55	38.9
M1 20	4424965	5784155	463	87.2	58.9	n.a.	0.24	6.60	0.94	n.a.	10.9	28.2	1.32	57.3
M1 21	4424994	5784155	334	111	80.4	n.a.	0.13	6.79	1.01	n.a.	13.3	31.6	1.46	51.7
M1 22	4425026	5784154	441	106	56.3	n.a.	0.06	7.03	0.93	n.a.	13.6	31.9	1.57	43.7
M1 23	4425056	5784153	150	134	83.2	50.0	0.87	6.50	1.05	n.a.	12.9	31.0	1.44	37.4
M1 24	4424964	5784125	205	89.0	58.2	32.0	0.36	6.50	0.87	n.a.	11.9	29.5	1.46	35.6
M1 25	4424995	5784122	231	102	57.6	n.a.	0.44	6.28	0.96	n.a.	12.6	30.5	1.37	37.5
M1 26	4425025	5784124	416	69.7	49.1	n.a.	0.16	6.48	0.85	n.a.	16.8	36.5	1.57	55.9
M1 27	4425054	5784123	360	133	83.5	n.a.	0.57	7.48	0.92	n.a.	16.7	36.3	1.43	43.0
M1 28	4425084	5784125	360	170	130	n.a.	0.32	7.28	1.12	n.a.	15.4	34.5	1.66	42.1
M1 29	4424964	5784094	264	71.6	49.9	n.a.	0.06	6.48	0.90	n.a.	16.0	35.4	1.64	35.7
M1 30	4424995	5784093	389	106	61.3	n.a.	0.51	6.70	0.80	n.a.	11.5	29.0	1.46	49.1
M1 31	4425024	5784092	571	144	85.2	46.7	0.65	7.31	0.98	n.a.	11.0	28.3	1.31	84.7
M1 32	4425054	5784094	240	132	92.2	n.a.	0.35	7.04	0.97	n.a.	18.3	38.6	1.64	48.1
M1 33	4425084	5784092	345	134	81.7	n.a.	0.38	7.24	0.79	n.a.	14.6	33.4	1.52	42.3
M1 34	4424965	5784065	442	91.7	50.8	n.a.	0.16	6.10	0.87	n.a.	15.9	35.2	1.72	43.6

Table A.5 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**CaCl$_2$-P** **mg kg^{-1}**	**pH**	**C$_{tot}$** **%**	**CaCO$_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
M1 35	4424995	5784062	347	87.2	43.8	n.a.	0.47	6.26	0.79	n.a.	11.3	28.8	1.23	44.4
M1 36	4425025	5784062	288	100	51.3	n.a.	0.30	6.90	0.86	n.a.	14.4	33.0	1.57	41.9
M1 37	4425054	5784063	322	157	94.5	n.a.	0.73	7.07	0.90	n.a.	16.0	35.3	1.66	42.4
M1 38	4425085	5784063	339	175	106	n.a.	0.66	6.68	0.85	n.a.	11.8	29.4	1.43	53.6
M1 39	4424964	5784034	369	93.6	54.3	n.a.	0.21	7.19	0.92	n.a.	14.4	33.1	1.57	43.2
M1 40	4424994	5784034	391	84.6	54.0	28.7	0.09	6.24	0.85	n.a.	14.9	33.8	1.65	44.8
M1 41	4425025	5784034	392	70.6	31.8	n.a.	0.27	6.33	0.79	n.a.	13.2	31.4	1.51	45.3
M1 42	4425055	5784034	338	173	87.5	n.a.	0.68	7.03	1.02	n.a.	13.1	31.3	1.57	49.5
M1 43	4425085	5784033	354	122	73.5	47.1	0.21	6.81	0.88	n.a.	15.3	34.4	1.66	81.7
M1 44	4424995	5784003	460	97.2	46.7	n.a.	0.19	6.12	0.83	n.a.	14.4	33.1	1.63	44.4
M1 45	4425024	5784003	354	97.2	41.1	n.a.	0.30	5.95	0.85	n.a.	12.8	30.8	0.93	43.8
M1 46	4425054	5784004	515	n.a.	49.3	n.a.	0.65	n.a	0.78	n.a.	15.5	34.6	1.66	43.4
M1 47	4425085	5784004	426	138	44.6	n.a.	0.19	7.18	0.90	n.a.	18.5	38.9	1.79	39.2
M1 48	4424994	5783973	430	89.9	95.1	n.a.	0.33	6.58	0.81	n.a.	15.2	34.3	1.61	51.6
M1 49	4425024	5783974	475	87.2	40.5	32.0	0.30	5.98	0.89	n.a.	14.3	33.0	1.30	43.6
M1 50	4425054	5783973	414	100	66.5	n.a.	0.17	7.18	0.86	n.a.	18.6	39.0	1.74	45.9
M1 51	4425085	5783973	388	139	90.4	n.a.	0.17	7.26	0.93	n.a.	17.0	36.8	1.51	39.3
M1 52	4425114	5783972	441	159	97.4	n.a.	0.35	7.10	0.98	n.a.	14.4	33.2	1.41	42.1
M1 53	4424995	5783944	529	62.4	28.9	n.a.	0.08	6.48	0.84	n.a.	13.7	32.2	1.41	48.9
M1 54	4425025	5783943	448	79.8	37.9	n.a.	0.06	6.51	0.83	n.a.	12.9	31.0	1.28	39.6
M1 55	4425054	5783944	384	163	103	n.a.	0.44	7.31	1.04	n.a.	22.5	44.5	1.68	50.2
M1 56	4425085	5783942	295	163	107	n.a.	0.08	7.23	0.99	n.a.	18.3	38.6	1.53	41.6
M1 57	4425115	5783942	375	316	197	n.a.	3.05	7.16	1.27	n.a.	13.4	31.6	1.25	41.1
M1 58	4424995	5783914	486	64.2	31.8	n.a.	0.19	6.40	0.78	n.a.	14.6	33.4	1.37	43.9
M1 59	4425025	5783914	490	90.8	41.4	n.a.	0.52	5.91	0.76	n.a.	11.2	28.6	1.18	50.0

Table A.5 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
M1 60	4425054	5783913	376	123	77.0	n.a.	0.55	6.67	0.96	n.a.	11.3	28.8	1.15	43.0
M1 61	4425084	5783912	441	173	98.6	61.0	0.62	7.27	1.13	n.a.	19.8	40.7	1.53	47.6
M1 62	4424995	5783884	391	142	64.2	41.0	0.43	6.76	0.84	n.a.	15.0	33.9	1.30	50.1
M1 63	4425025	5783884	510	91.7	52.5	n.a.	0.27	6.78	0.81	n.a.	13.0	31.1	1.20	50.8
M1 64	4425055	5783884	310	110	55.1	n.a.	0.43	6.37	0.94	n.a.	11.9	29.6	1.22	45.9
M1 65	4424997	5783854	328	151	154	n.a.	0.32	7.24	0.90	n.a.	21.2	42.6	1.46	43.7
M1 66	4425025	5783852	410	280	91.6	n.a.	0.30	7.39	1.28	n.a.	25.8	49.2	1.65	51.9
M2 2	4424780	5784214	469	174	108	53.6	0.89	6.60	0.97	1.38	13.9	32.4	1.43	42.0
M2 3	4424789	5784183	416	163	103	n.a.	0.88	6.42	1.09	0.29	12.6	30.6	1.22	42.4
M2 4	4424795	5784155	468	171	90.6	n.a.	1.37	6.33	1.17	0.25	11.3	28.7	1.32	47.6
M2 5	4424803	5784126	472	160	93.9	n.a.	1.09	6.60	1.16	0.43	11.4	28.8	1.42	57.3
M2 6	4424808	5784097	477	185	125	n.a.	0.91	6.89	1.22	0.46	11.0	28.3	1.45	45.0
M2 7	4424813	5784067	400	130	83.4	n.a.	0.71	6.98	1.05	0.42	14.8	33.6	1.56	44.1
M2 8	4424820	5784039	372	115	75.9	n.a.	0.48	7.14	1.10	0.41	18.4	38.7	1.67	47.1
M2 9	4424823	5784010	389	122	78.8	n.a.	0.53	7.11	1.17	0.54	15.4	34.5	1.65	48.8
M2 10	4424833	5783976	328	108	57.9	n.a.	0.23	7.21	1.02	0.49	16.6	36.2	1.63	43.1
M2 11	4424835	5783951	499	166	93.1	n.a.	0.33	7.54	1.27	1.58	21.7	43.4	1.77	60.7
M2 12	4424842	5783924	377	230	104	n.a.	0.43	7.45	1.09	0.71	17.2	37.1	1.60	48.5
M2 13	4424848	5783892	416	163	93.5	n.a.	0.51	7.46	< 0.01	0.64	16.8	36.6	1.58	44.0
M2 14	4424854	5783860	388	114	68.3	n.a.	0.25	7.31	1.07	0.33	16.8	36.4	1.63	45.0
M2 15	4424861	5783828	334	123	79.7	n.a.	0.43	7.14	0.92	2.77	13.0	31.1	1.34	44.5
M2 16	4424867	5783799	402	162	90.7	38.9	0.63	6.65	1.05	0.69	12.2	30.0	1.29	48.1
M2 17	4424873	5783773	376	160	102	n.a.	0.50	7.29	1.09	0.76	16.4	35.9	1.49	42.9
M2 18	4424872	5783749	452	147	98	n.a.	0.38	7.31	0.91	0.75	17.6	37.7	1.56	42.6
M2 19	4424883	5783714	353	149	86.4	n.a.	0.41	7.06	0.95	0.47	14.9	33.9	1.40	38.9
M2 20	4424890	5783687	307	141	95.6	n.a.	0.46	7.23	0.97	0.97	15.0	34.0	1.43	36.1

Table A.5 continued

Sample	**Easting** **m**	**Northing** **m**	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**CAL** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**pH**	**C_{tot}** **%**	**$CaCO_3$** **%**	**Clay** **%**	**Rb** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
M2 21	4424896	5783659	530	224	140	n.a.	1.18	6.86	1.23	0.64	14.1	32.8	1.39	40.9
M2 22	4424920	5783695	331	158	88.1	n.a.	0.50	7.32	1.11	0.85	20.3	41.5	1.59	39.7
M2 23	4424913	5783717	411	162	93.5	n.a.	0.88	6.94	1.17	0.79	15.0	34.0	1.38	40.1
M2 24	4424907	5783744	451	196	136	n.a.	1.64	7.12	1.02	0.76	14.6	33.4	1.30	40.1
M2 25	4424900	5783765	427	227	127	n.a.	1.16	7.10	1.05	0.46	14.5	33.3	1.35	46.7
M2 26	4424894	5783805	476	187	115	n.a.	1.33	7.04	1.01	0.30	13.0	31.2	1.45	50.8
M2 27	4424888	5783832	425	186	114	n.a.	1.79	6.62	1.17	1.29	9.7	26.5	1.29	43.2
M2 28	4424881	5783864	426	194	123	63.1	1.01	7.01	1.11	0.43	13.7	32.1	1.47	47.8
M2 29	4424876	5783893	449	193	126	n.a.	0.86	7.43	1.31	1.46	24.2	46.9	1.91	54.5
M2 30	4424870	5783923	408	161	107	n.a.	0.53	7.33	1.03	0.44	19.3	40.0	1.81	45.1
M2 31	4424864	5783951	409	203	113	n.a.	1.39	6.89	1.04	0.30	11.1	28.5	1.43	43.2
M2 32	4424857	5783980	344	161	90.3	n.a.	0.78	6.81	1.01	0.40	14.2	32.9	1.58	42.6
M2 33	4424852	5784009	431	173	96.6	n.a.	1.03	6.94	0.97	0.62	16.1	35.4	1.66	47.1
M2 34	4424846	5784039	498	187	107	n.a.	1.18	6.85	0.95	0.21	15.1	34.1	1.68	48.7
M2 34a	4424841	5784069	501	169	111	n.a.	1.03	7.02	0.91	0.26	17.8	37.9	1.72	47.8
M2 35	4424834	5784099	598	256	145	n.a.	1.72	6.79	1.19	0.34	15.4	34.5	1.43	51.2
M2 36	4424828	5784131	681	262	153	n.a.	1.26	7.09	1.30	0.53	21.1	42.6	1.61	75.0
M2 37	4424823	5784160	583	259	149	71.2	1.51	6.89	1.19	0.66	22.2	44.2	1.59	76.6
M2 38	4424817	5784186	627	234	143	n.a.	1.18	6.91	1.17	0.50	19.2	39.8	1.57	51.7
M2 39	4424812	5784219	907	263	115	n.a.	0.27	7.49	2.59	1.67	35.9	63.4	2.87	67.5
M2 40	4424841	5784226	665	222	134	n.a.	1.01	6.63	1.07	0.40	19.8	40.7	1.73	50.7
M2 42	4424847	5784198	508	220	140	n.a.	1.33	6.68	1.33	0.47	18.7	39.1	1.46	50.8
M2 43	4424852	5784169	556	254	155	n.a.	2.58	6.51	1.24	3.17	19.2	39.8	1.43	58.6
M2 44	4424858	5784140	466	202	120	n.a.	1.33	6.81	1.21	0.42	19.5	40.2	1.50	52.8
M2 45	4424864	5784106	481	204	126	68.0	1.56	6.88	1.21	0.43	14.2	32.9	1.40	58.6
M2 46	4424870	5784075	358	138	73.4	n.a.	0.70	6.64	0.88	0.36	16.7	36.3	1.74	45.3

Table A.5 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**CaCl$_2$-P** mg kg^{-1}	**pH**	**C$_{tot}$** %	**CaCO$_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
M2 47	4424873	5784036	428	169	90.3	n.a.	1.04	6.64	1.00	0.29	16.5	36.0	1.66	47.2
M2 48	4424883	5784016	439	138	62.4	n.a.	0.83	6.19	0.93	0.49	16.5	36.0	1.65	45.7
M2 49	4424886	5783983	338	164	84.4	n.a.	1.21	6.40	0.97	0.34	12.4	30.3	1.45	39.3
M2 50	4424890	5783953	445	155	86.1	n.a.	1.33	6.55	0.97	0.40	14.5	33.2	1.61	49.0
M2 51	4424899	5783932	612	210	144	n.a.	0.96	6.94	1.04	2.76	21.7	43.4	1.83	57.8
M2 52	4424907	5783902	473	206	118	n.a.	1.49	6.72	1.02	0.21	13.3	31.5	1.46	48.1
M2 53	4424912	5783873	565	199	139	n.a.	1.37	6.99	1.07	0.52	14.9	33.8	1.54	50.5
M2 54	4424918	5783838	462	223	157	n.a.	0.66	7.10	1.06	1.61	22.6	44.7	1.78	53.4
M2 55	4424923	5783810	458	209	139	n.a.	0.83	6.85	1.00	< 0.01	17.9	38.0	1.64	55.2
M2 56	4424929	5783780	416	209	121	n.a.	0.70	7.00	1.05	0.12	21.9	43.7	1.70	49.3
M2 57	4424936	5783748	426	188	119	n.a.	0.63	7.03	1.08	0.13	21.1	42.6	1.66	46.1
M2 58	4424943	5783720	472	233	151	n.a.	1.41	7.30	1.14	0.30	18.8	39.4	1.46	47.5
M2 59	4424965	5783744	562	175	109	n.a.	0.53	7.13	1.06	0.30	18.2	38.5	1.55	46.6
M2 60	4424958	5783777	437	195	119	61.8	0.86	7.07	1.07	0.41	14.5	33.2	1.31	49.9
M2 61	4424953	5783810	311	203	147	n.a.	0.96	7.17	1.16	0.47	21.8	43.5	1.66	48.7
M2 62	4424946	5783836	400	162	99.2	n.a.	0.63	6.93	1.01	0.76	15.8	35.1	1.46	47.8
M2 63	4424940	5783874	364	171	106	n.a.	1.29	6.64	1.04	0.72	14.3	33.0	1.29	45.0
M2 64	4424935	5783901	270	183	110	n.a.	1.14	7.00	1.05	0.34	14.9	33.8	1.33	39.2
M2 65	4424929	5783931	333	182	109	n.a.	0.94	6.84	0.94	0.21	17.8	37.9	1.76	42.0
M2 66	4424923	5783958	404	216	133	n.a.	1.37	6.72	1.02	0.21	13.7	32.1	1.39	40.3
M2 67	4424916	5783986	544	184	108	n.a.	1.64	6.66	0.90	0.13	10.4	27.5	1.20	42.7
M2 68	4424911	5784015	385	143	80.6	n.a.	1.01	6.69	0.96	0.43	12.1	29.8	1.25	39.4
M2 69	4424905	5784043	483	172	97.0	53.6	1.04	6.52	0.90	0.20	14.1	32.8	1.55	44.3
M2 70	4424898	5784072	465	n.a.	93.2	n.a.	1.03	6.58	0.94	0.46	15.1	34.1	1.59	47.4
M2 91	4424892	5784104	472	252	145	n.a.	1.76	6.72	1.09	0.35	12.9	31.0	1.43	53.6
M2 92	4424885	5784139	523	254	152	n.a.	1.62	6.87	1.24	0.21	17.0	36.8	1.61	54.9

Table A.5 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**CaCl$_2$-P** mg kg^{-1}	**pH**	**C$_{tot}$** %	**CaCO$_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
M2 93	4424880	5784169	559	278	173	n.a.	1.79	6.85	1.19	0.23	17.1	36.9	1.52	53.9
M2 94	4424876	5784196	552	290	191	86.8	1.92	6.90	1.24	0.17	17.5	37.5	1.47	49.1
M2 95	4424870	5784224	502	281	178	n.a.	1.29	7.02	1.11	0.16	18.4	38.8	1.63	49.1
M2 96	4424900	5784229	351	100	56.1	n.a.	0.45	7.10	1.05	0.28	20.1	41.1	1.59	43.8
M2 97	4424906	5784201	350	122	60.3	n.a.	0.61	6.69	1.12	0.24	19.5	40.2	1.52	44.5
M2 98	4424909	5784175	438	137	69.6	n.a.	1.26	6.34	1.12	0.26	16.3	35.8	1.41	46.4
M2 99	4424915	5784146	466	157	92.8	n.a.	1.51	6.48	1.15	0.17	16.3	35.8	1.49	48.8
M2 100	4424922	5784110	373	124	68.4	n.a.	0.76	6.85	0.98	0.17	12.2	30.0	1.46	45.4
M2 101	4424929	5784078	298	98.5	59.1	n.a.	0.65	6.80	0.93	1.07	11.5	29.1	1.42	39.2
M2 102	4424934	5784047	300	126	67.1	n.a.	0.58	7.30	0.90	n.a.	14.7	33.5	1.51	41.4
M2 103	4424942	5784019	286	107	78.9	n.a.	0.53	7.45	1.01	n.a.	18.2	38.5	1.63	39.4
M2 104	4424948	5783990	358	109	54.0	31.1	0.43	7.03	0.88	n.a.	13.3	31.5	1.38	37.9
M2 105	4424954	5783963	307	102	47.7	n.a.	0.76	6.54	0.97	n.a.	11.5	28.9	1.38	36.6
M2 106	4424960	5783935	369	120	56.5	n.a.	1.01	6.45	0.93	n.a.	10.5	27.6	1.41	40.0
M2 107	4424966	5783905	319	109	52.3	n.a.	1.03	6.20	1.02	n.a.	10.5	27.6	1.33	39.5
M2 108	4424971	5783876	336	124	71.3	n.a.	0.94	6.71	0.98	n.a.	10.9	28.2	1.36	40.4
M2 109	4424978	5783838	375	178	97.0	n.a.	1.04	7.07	1.06	n.a.	17.7	37.8	1.56	44.0
M2 110	4424984	5783814	334	119	65.8	n.a.	0.51	6.77	0.94	n.a.	12.5	30.4	1.40	41.6
M2 111	4424991	5783779	382	148	94.5	n.a.	0.71	6.97	1.04	n.a.	10.1	27.0	1.41	43.1
M2 112	4425001	5783816	437	134	96.6	n.a.	1.18	6.92	0.86	n.a.	10.0	26.9	1.41	46.8
M2 113	4424995	5783841	603	228	135	n.a.	0.61	7.56	1.18	n.a.	24.8	47.8	2.07	50.1
M2 114	4424987	5783880	420	106	73.8	n.a.	0.46	7.10	0.83	n.a.	14.6	33.4	1.54	41.9
M2 115	4424983	5783908	326	94.5	59.1	n.a.	0.58	6.78	0.84	n.a.	13.1	31.3	1.52	39.4
M2 116	4424976	5783938	310	80.7	52.3	n.a.	0.51	6.87	0.83	n.a.	13.9	32.4	1.61	39.8
M2 117	4424971	5783965	344	100	58.2	n.a.	n.a.	6.94	0.89	n.a.	14.0	32.6	1.61	41.4
M2 118	4424965	5783993	284	79.8	47.7	n.a.	0.40	6.95	0.83	n.a.	15.3	34.4	1.66	42.6

Table A.5 continued

Sample	**Easting m**	**Northing m**	**AR-P mg kg^{-1}**	**WH-P mg kg^{-1}**	**AAC-P mg kg^{-1}**	**CAL mg kg^{-1}**	**$CaCl_2$-P mg kg^{-1}**	**pH**	**C_{tot} %**	**$CaCO_3$ %**	**Clay %**	**Rb mg kg^{-1}**	**Fe g kg^{-1}**	**Zn mg kg^{-1}**
M2 119	4424960	5784022	380	114	71.7	n.a.	0.53	7.33	0.92	n.a.	19.0	39.6	1.83	46.9
M2 120	4424954	5784049	441	87.2	64.1	n.a.	0.43	7.16	0.86	n.a.	15.0	34.0	1.67	48.3
M2 121	4424948	5784079	368	80.7	55.7	n.a.	0.58	n.a.	0.85	n.a.	16.1	35.4	1.72	44.5
M2 122	4424940	5784113	392	98.2	55.7	n.a.	0.35	n.a.	0.81	n.a.	11.8	29.4	1.52	41.3
M2 123	4424935	5784153	407	147	83.1	n.a.	0.70	n.a.	0.98	n.a.	11.0	28.3	1.45	52.3
M2 124	4424927	5784182	382	103	64.1	n.a.	1.64	n.a.	0.92	n.a.	14.4	33.1	1.55	43.3
M2 125	4424920	5784210	396	129	60.8	n.a.	0.96	n.a.	0.90	n.a.	18.7	39.2	1.66	48.9
M2 126	4424916	5784234	427	91.7	47.7	n.a.	0.53	n.a.	0.86	n.a.	20.3	41.4	1.92	46.4
M3 1	4425115	5783915	792	309	225	n.a.	2.94	7.26	1.23	0.62	12.9	31.0	1.67	50.9
M3 2	4425086	5783882	565	203	118	70.0	0.87	7.41	1.05	0.37	18.6	39.0	1.95	49.9
M3 3	4425115	5783884	594	250	161	n.a.	1.35	7.22	1.02	0.46	17.1	36.8	1.85	46.8
M3 4	4425054	5783854	588	224	140	n.a.	0.84	7.29	0.95	0.71	17.1	36.9	1.84	48.1
M3 5	4425085	5783852	556	189	112	n.a.	0.73	7.23	1.87	0.76	16.4	35.9	2.00	46.3
M3 7	4425024	5783823	480	205	111	n.a.	0.43	7.24	0.84	0.17	16.6	36.2	1.95	52.3
M3 8	4425054	5783824	616	199	118	63.5	0.56	7.48	0.95	0.25	19.3	40.0	2.07	53.7
M3 9	4425085	5783823	588	196	108	n.a.	1.12	7.05	0.98	0.25	15.6	34.8	1.86	51.4
M3 10	4425114	5783824	499	183	101	74.1	0.68	7.52	1.39	1.39	11.1	28.4	1.61	48.0
M3 12	4425025	5783796	635	218	140	n.a.	0.84	7.33	0.99	0.13	19.0	39.6	1.97	53.7
M3 13	4425054	5783794	716	342	149	n.a.	0.51	7.60	1.02	0.84	25.3	48.5	2.31	71.7
M3 14	4425085	5783792	611	225	94.9	n.a.	0.65	7.55	1.45	2.68	16.0	35.3	1.68	47.1
M3 16	4424994	5783762	537	202	130	n.a.	0.87	7.32	1.01	0.20	15.0	33.9	1.55	45.0
M3 17	4425025	5783764	834	515	131	81.9	0.46	7.59	1.06	1.42	32.9	59.2	2.73	74.8
M3 18	4425055	5783764	477	195	116	n.a.	1.01	7.49	1.31	1.13	14.0	32.6	1.64	45.8
M3 20	4424964	5783733	516	161	106	n.a.	0.82	7.12	1.08	0.20	14.4	33.2	1.69	42.6
M3 21	4424994	5783735	586	260	127	n.a.	0.51	7.58	1.12	1.15	24.1	46.8	2.29	55.6
M3 22	4425025	5783735	416	145	94.9	n.a.	0.71	7.24	1.09	0.08	16.0	35.4	1.73	43.0

Table A.5 continued

Sample	**Easting** m	**Northing** m	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**CAL** mg kg^{-1}	**$CaCl_2$-P** mg kg^{-1}	**pH**	**C_{tot}** %	**$CaCO_3$** %	**Clay** %	**Rb** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
M3 23	4425055	5783735	n.a.	23.8	59.2	59.4	0.09	7.76	6.76	44.9	n.a.	n.a.	n.a.	n.a.
M3 25	4424966	5783704	759	416	114	n.a.	0.90	7.70	1.29	3.31	31.7	57.5	2.42	52.9
M3 26	4424995	5783704	370	134	85.1	52.0	0.54	7.13	0.95	0.46	16.4	35.9	1.82	45.2
M3 27	4425025	5783705	426	222	104	n.a.	0.93	7.49	1.70	3.22	11.0	28.3	1.45	43.5
M3 29	4424934	5783674	479	221	132	n.a.	0.87	7.63	0.98	0.50	20.3	41.4	1.93	44.8
M3 30	4424965	5783675	525	254	137	n.a.	0.46	7.44	1.02	0.62	23.7	46.2	2.06	46.3
M3 31	4424994	5783674	386	146	74.4	n.a.	1.10	6.41	1.04	0.21	8.6	25.0	1.66	41.7
M3 33	4424905	5783644	381	174	113	83.9	0.96	7.61	1.07	0.97	12.2	30.0	1.46	38.2
M3 34	4424935	5783645	426	154	97.2	n.a.	0.77	6.71	1.06	0.37	13.1	31.3	1.67	44.3
M3 35	4424965	5783644	n.a.	126	60.1	38.9	0.77	6.14	1.05	0.25	10.9	28.2	1.54	n.a.
M3 37	4424875	5783616	439	208	141.8	n.a.	1.60	7.11	1.20	0.20	8.5	24.7	0.89	37.9
M3 38	4424904	5783614	385	138	81.3	n.a.	0.84	6.68	1.02	0.42	11.4	28.9	1.12	41.9
M3 39	4424934	5783615	390	172	94.9	50.35	0.87	6.98	n.a.	0.69	16.0	35.4	0.98	42.7
M3 41	4424875	5783583	356	143	99.7	n.a.	0.62	7.12	1.02	0.33	18.4	38.8	1.24	41.9
M3 42	4424905	5783583	593	282	45.3	n.a.	0.23	7.63	2.09	6.98	30.0	55.1	1.66	50.6
M3 44	4424834	5783543	497	240	82.9	n.a.	0.29	7.57	1.49	1.80	25.9	49.3	1.59	48.7
M3 45	4424814	5783551	434	168	104	n.a.	0.31	7.50	1.08	0.37	22.0	43.8	1.63	48.1
M3 46	4424875	5783553	828	514	135	n.a.	0.79	7.58	2.07	4.62	24.5	47.3	1.48	57.9
M3 47	4424937	5783565	565	250	158	n.a.	1.02	7.45	1.28	0.69	20.5	41.6	1.76	50.5

n.a. = not analysed/not available

Tab. A.6: Results of chemical soil analysis for grid samples from Ceveiro (W74º47', S22º 40').

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C_{org}**
	m	**m**	**%**	**%**	**%**			**$mmol_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
1001	214529	7492231	78	8	14	1.0	26	5	0	34	94	0	5.5	8
1002	214793	7492199	76	8	16	0.6	14	4	10	45	42	35	4.5	13
1003	215210	7492338	71	11	18	2.5	10	4	26	87	19	61	3.8	10
1004	215458	7491897	76	8	16	1.9	14	4	6	34	59	23	4.5	15
1005	215472	7491541	24	39	37	2.0	36	7	2	73	62	4	4.6	23
1006	215672	7491629	47	31	22	1.1	25	6	3	60	53	9	4.6	28
1007	216046	7491183	68	18	14	2.2	19	6	3	39	69	10	4.6	13
1008	216382	7491095	86	8	6	0.3	3	1	7	22	19	62	4.0	15
1009	216116	7491522	43	33	24	3.3	11	2	12	54	30	42	4.1	20
1010	215914	7491713	41	35	24	1.3	18	7	2	46	57	7	4.6	13
1011	215689	7492012	55	23	22	6.2	21	9	6	64	56	14	4.4	13
1012	215371	7492516	84	10	6	1.3	3	1	6	15	35	53	3.7	8
1015	217094	7493187	90	8	2	0.8	2	1	6	13	30	61	4.0	8
1016	216380	7493357	86	8	6	1.7	1	2	6	45	11	56	4.1	8
1017	216484	7493156	72	12	16	1.5	17	8	13	107	25	33	4.4	15
1018	216706	7493039	80	10	10	1.5	10	6	7	36	49	29	4.3	13
1019	216933	7493773	73	11	16	0.9	22	7	6	60	50	17	4.5	15
1020	217094	7493187	80	12	8	2.4	17	6	11	67	38	30	4.1	5
1021	217365	7492795	64	22	14	1.0	12	6	3	29	66	14	4.8	10
1022	217481	7492610	54	20	26	1.1	13	4	7	66	27	28	4.2	23
1023	217735	7492241	22	45	33	8.1	50	20	0	138	57	0	5.1	22
1024	217602	7491930	52	30	18	3.7	19	10	1	43	77	3	4.8	13
1025	218089	7491846	51	26	23	6.1	51	13	0	110	64	0	5.8	13
1026	218328	7491907	70	20	10	2.4	14	4	6	28	72	23	5.1	8
1027	218849	7492074	19	33	48	12.2	99	36	0	175	84	0	5.2	23
1028	218551	7492728	21	35	44	5.2	60	18	0	123	68	0	5.0	23

Table A.6 continued

Sample	**Westing** m	**Southing** m	**Sand** %	**Silt** %	**Clay** %	**K$^+$**	**Ca^{2+}**	**Mg^{2+}** mmol$_c$ kg^{-1}	**Al^{3+}**	**CEC**	**B. sat** %	**Al. sat** %	**pH**	**C$_{org}$** g kg^{-1}
1029	218697	7493168	49	27	24	1.4	19	7	12	147	19	30	4.1	15
1030	219316	7492002	35	41	24	1.9	21	6	2	59	49	6	4.6	20
1031	219427	7491929	24	37	39	4.3	53	18	0	127	59	0	4.9	28
1032	220057	7492050	23	42	35	5.8	84	15	0	135	78	0	5.1	20
1033	219807	7492274	21	35	44	3.3	90	21	0	172	66	0	5.0	26
1034	220098	7492207	23	35	42	2.8	69	16	6	152	58	6	4.4	26
1036	219281	7493010	19	41	40	6.1	54	22	1	124	66	1	4.8	23
1037	219822	7493244	49	25	26	5.0	33	10	0	70	69	0	5.0	20
1038	219120	7493520	41	31	28	4.7	24	7	5	66	54	12	4.4	23
1039	218783	7493313	16	53	31	1.7	37	18	0	81	70	0	5.2	23
1040	219100	7494109	13	45	42	3.2	32	13	9	196	25	16	4.4	23
1041	219110	7494460	30	36	34	1.7	25	8	20	115	30	37	4.0	13
1042	219689	7494603	40	29	31	0.8	30	6	2	107	34	5	4.5	20
1043	219270	7492736	26	33	41	2.3	46	15	6	197	32	9	3.9	8
1044	220547	7492892	14	36	50	2.5	2	15	177	220	9	90	3.6	6
1045	220461	7493237	22	40	38	8.6	68	16	2	116	80	2	4.9	13
1046	220865	7493082	11	31	58	9.5	99	28	16	247	55	10	4.2	24
1048	220757	7494425	51	18	31	5.8	29	7	0	76	55	0	5.2	18
1049	220768	7494129	30	35	35	3.0	42	11	2	108	52	3	4.5	31
1050	219780	7495131	64	14	22	1.0	18	5	4	62	39	14	4.4	15
1051	219331	7495238	78	12	10	0.8	10	3	10	51	27	42	3.8	13
1052	218761	7495042	76	12	12	0.7	9	3	6	39	33	32	4.0	13
1053	218415	7494744	80	14	6	0.5	14	6	0	33	63	0	5.1	13
1054	218635	7495836	76	14	10	0.6	11	3	4	37	40	22	4.4	10
1055	218459	7495722	82	10	8	0.4	5	1	8	30	21	56	4.0	10
1056	218348	7495094	40	29	31	1.0	45	10	0	92	61	0	4.9	20

Table A.6 continued

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C$_{org}$**
	m	**m**	**%**	**%**	**%**			**mmol$_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
1057	218014	7494750	61	19	20	1.8	19	4	14	76	33	36	4.0	15
1058	217880	7495506	47	28	25	4.5	27	7	76	133	29	66	4.0	10
1059	215323	7491114	13	33	54	4.8	24	9	43	116	33	53	3.9	23
1060	214987	7491474	30	41	29	2.4	47	12	6	103	59	9	4.4	23
1061	214872	7491368	26	42	32	1.7	205	16	0	235	95	0	5.3	26
1062	216817	7491408	66	22	12	2.6	28	5	0	56	64	0	4.9	18
1063	216464	7491782	62	22	16	1.1	23	6	2	56	54	6	4.6	20
1064	216192	7491886	30	31	39	3.3	32	14	1	75	65	2	4.8	18
1065	216852	7491937	49	24	27	2.1	38	11	0	79	65	0	4.9	20
1066	221120	7493402	36	31	33	12.0	85	26	0	140	88	0	5.7	36
1067	220118	7494278	35	36	29	4.4	72	16	2	130	71	2	4.7	20
1068	219754	7494101	22	36	42	2.5	64	19	0	111	77	0	4.9	18
1069	220479	7494141	27	38	35	4.1	39	11	2	86	63	4	4.7	20
1070	219317	7494016	43	30	27	2.7	20	7	8	70	43	21	4.2	18
1071	218696	7493942	22	40	38	1.9	38	28	6	134	51	8	4.4	17
1072	217572	7495321	80	12	8	2.0	4	2	14	42	19	64	3.7	13
1073	217582	7495090	84	10	6	1.8	3	2	22	58	12	76	3.7	10
1074	217658	7494741	64	20	16	0.8	8	2	10	71	15	48	4.0	18
1075	217383	7494965	82	12	6	1.5	5	2	4	27	32	32	4.3	15
1076	217624	7494651	48	23	29	1.1	51	19	0	105	68	0	5.3	15
1077	217505	7494678	73	13	14	2.5	17	6	2	57	45	7	4.7	18
1078	217405	7494373	86	10	4	1.8	7	3	3	30	40	20	4.4	10
1079	216972	7494536	88	8	4	1.8	12	5	3	41	46	14	4.5	18
1080	217471	7494182	56	28	16	1.4	24	9	0	60	57	0	5.0	18
1081	217712	7493870	43	20	37	3.8	40	18	0	92	67	0	5.0	18
1082	215891	7490851	27	40	33	18.9	83	14	4	196	59	3	4.4	30

Table A.6 continued

Sample	**Westing** **m**	**Southing** **m**	**Sand** **%**	**Silt** **%**	**Clay** **%**	**K^+**	**Ca^{2+}**	**Mg^{2+}** **$mmol_c\ kg^{-1}$**	**Al^{3+}**	**CEC**	**B. sat** **%**	**Al. sat** **%**	**pH**	**C_{org}** **$g\ kg^{-1}$**
1083	216547	7491227	51	6	43	5.9	23	16	18	125	36	29	4.2	14
1084	216357	7491526	52	26	22	1.7	27	13	0	74	57	0	5.1	15
1085	216286	7491552	18	47	35	3.5	46	19	0	99	70	0	4.9	15
1086	215635	7491289	33	40	27	3.2	11	4	17	84	22	48	3.9	28
1087	215366	7491701	46	33	21	3.5	57	12	3	103	71	4	4.5	13
1088	215088	7491952	58	22	20	2.0	12	5	31	75	25	62	3.8	18
1089	214647	7491861	84	8	8	2.2	8	2	4	34	36	25	4.1	10
1090	214849	7491874	76	12	12	1.1	13	4	9	48	38	33	3.9	13
1091	217534	7492542	41	16	43	14.4	65	22	0	131	77	0	5.6	10
1092	217365	7493456	84	10	6	1.0	13	4	3	81	22	14	4.2	5
1093	216768	7494425	86	6	8	0.8	26	9	1	66	54	3	4.6	8
1094	217698	7493410	35	32	33	2.9	38	17	9	171	34	13	4.1	10
1095	218084	7493268	31	41	28	3.6	32	12	1	143	33	2	4.5	23
1096	218334	7493177	29	47	24	1.0	21	5	8	141	19	23	4.0	15
1097	218611	7492420	28	31	41	8.4	67	24	0	173	57	0	5.2	15
1098	218019	7492733	27	33	40	11.4	70	28	3	216	51	3	4.4	15
1099	218076	7493018	27	40	33	3.4	38	14	3	159	35	5	4.4	23
1100	216527	7493786	84	8	8	0.9	18	7	6	72	36	19	4.2	3
1101	221493	7493467	41	22	37	8.4	91	27	0	187	67	0	5.3	32
1102	216683	7493632	82	10	8	2.2	30	13	1	80	56	2	4.8	9
1103	217982	7491722	62	20	18	6.2	62	18	0	112	77	0	5.6	17
1105	216442	7490949	80	8	12	2.9	11	3	6	46	37	26	4.1	8
1106	216259	7491078	80	6	14	2.4	4	2	13	40	21	61	3.8	10
1107	216070	7491292	62	16	22	3.8	111	95	0	218	96	0	6.5	24
1108	216070	7491292	62	20	18	3.1	39	23	0	78	83	0	5.9	22
1109	215916	7491576	31	38	31	5.8	23	14	10	93	46	19	4.3	36

Table A.6 continued

Sample	Westing m	Southing m	Sand %	Silt %	Clay %	K^+	Ca^{2+}	Mg^{2+} mmol$_c$ kg^{-1}	Al^{3+}	CEC	B. sat %	Al. sat %	pH	C_{org} g kg^{-1}
1110	215581	7491957	82	4	14	2.7	17	4	11	60	40	32	3.8	11
1111	215432	7493218	82	8	10	1.1	43	9	0	71	75	0	5.1	6
1112	215295	7492874	84	8	8	0.7	16	3	4	48	41	17	4.1	6
1113	219506	7494423	26	29	45	3.3	65	16	0	118	71	0	5.0	5
1114	219943	7494827	21	17	62	0.8	49	10	0	102	59	0	5.9	5
1115	217821	7494164	55	23	22	7.3	89	30	0	180	70	0	5.7	26
1116	218133	7494057	62	20	18	2.4	27	11	0	80	50	0	4.9	5
1117	218148	7493743	19	33	48	6.0	54	17	8	131	59	9	4.5	15
1118	218267	7493647	13	29	58	3.9	76	19	1	147	67	1	4.8	15
1119	218136	7493601	23	44	33	1.8	38	13	1	97	55	2	4.8	31
1120	220264	7492772	72	18	10	3.2	40	6	0	73	67	0	5.3	10
1121	219924	7493129	70	18	12	4.1	14	4	1	56	39	4	4.8	5
1122	217139	7493625	88	6	6	1.7	8	4	6	40	35	30	4.4	5
1123	217028	7493214	86	6	8	1.5	8	4	5	44	31	27	4.3	5
1124	217398	7493041	35	31	34	2.0	24	8	14	88	39	29	4.1	15
1125	217662	7492955	36	23	41	4.1	42	23	8	117	59	10	4.6	5
1126	217269	7491679	45	27	28	2.9	32	10	6	99	45	12	4.5	31
1127	217239	7491765	45	29	26	2.2	25	7	3	84	41	8	4.5	5
1128	217149	7492042	52	24	24	1.7	34	11	2	95	49	4	4.6	36
1129	217012	7492005	35	32	33	2.0	43	13	0	96	60	0	4.9	28
1130	217347	7492130	32	35	33	3.2	43	13	2	107	55	3	4.6	28
1131	217141	7492266	30	37	33	11.7	70	20	0	138	74	0	4.9	10
1132	217015	7492364	29	38	33	2.7	32	7	9	92	45	18	4.2	13
2001	216570	7492770	47	19	34	4.0	64	20	1	138	64	1	4.8	17
2002	216173	7492815	82	8	10	1.8	5	3	9	62	16	48	4.0	3

Table A.6 continued

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C$_{org}$**
	m	**m**	**%**	**%**	**%**			**mmol$_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
2003	216131	7492771	84	6	10	1.8	4	3	9	51	17	51	3.9	14
2004	216468	7493858	82	10	8	1.8	32	7	0	57	72	0	5.0	16
2005	216393	7493719	84	8	8	3.5	19	4	4	58	46	13	4.3	14
2006	216351	7493705	80	8	12	5.3	19	6	16	77	39	35	4.0	20
2007	216493	7490959	78	10	12	4.2	9	2	3	42	36	16	4.2	6
2008	215939	7491588	52	28	20	3.8	35	17	1	80	70	2	4.5	22
2009	215781	7491694	41	29	30	4.9	16	6	18	80	34	40	3.8	11
2010	215943	7491861	62	22	16	2.1	4	1	21	55	13	75	3.8	23
2011	215389	7492269	78	8	14	2.3	51	13	1	89	74	1	4.6	3
2012	215350	7492669	90	2	8	0.9	8	2	0	39	28	0	4.0	21
2013	220088	7492899	76	16	8	1.6	10	2	3	40	34	18	4.4	10
2014	219559	7493406	14	29	57	10.9	101	23	0	158	85	0	5.7	10
2015	219366	7493641	24	41	35	3.8	29	10	3	94	46	7	4.5	18
2016	219342	7493881	40	30	30	2.4	31	9	6	86	49	12	4.3	15
2017	219195	7494062	22	33	45	3.5	93	37	0	148	91	0	5.9	18
2018	218946	7494174	22	33	45	1.3	61	15	0	105	73	0	5.4	20
2019	220461	7494374	58	26	16	2.1	18	5	3	59	42	11	4.5	10
2020	219995	7494137	26	40	34	5.0	38	8	4	91	56	7	4.4	13
2021	219773	7494103	18	39	43	4.1	111	44	0	169	94	0	6.2	18
2022	218666	7495244	74	14	12	0.7	2	2	9	31	15	66	3.9	8
2023	218811	7494435	46	28	26	2.5	8	4	4	42	35	22	4.3	18
2024	218784	7494884	72	18	10	1.3	1	2	13	40	11	75	3.9	5
2025	216801	7494120	84	8	8	1.0	2	2	5	27	19	50	4.2	5
2026	217172	7493099	80	10	10	2.4	6	3	9	45	25	44	3.9	5
2027	217299	7492877	47	25	28	7.1	62	21	0	130	69	0	5.6	28
2029	217764	7492063	54	18	28	6.5	140	56	0	221	92	0	6.1	23

Table A.6 continued

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C$_{org}$**
	m	**m**	**%**	**%**	**%**			**mmol$_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
2030	217866	7491812	60	18	22	5.1	47	26	0	106	74	0	5.8	26
3001	215468	7491222	13	52	35	5.1	48	12	6	145	45	8	4.4	44
3002	215619	7491321	34	43	23	3.5	20	5	2	89	32	7	4.3	24
3003	215682	7491728	36	39	25	14.3	69	27	0	144	76	0	5.3	52
3004	215692	7491662	67	17	16	0.8	23	7	0	79	39	0	4.7	19
3005	215614	7491667	45	35	20	1.1	34	10	0	101	45	0	4.9	32
3006	216176	7491944	54	26	20	1.1	9	3	10	83	16	43	4.0	14
3007	216303	7492167	71	15	14	1.2	9	3	6	56	23	31	4.1	19
3008	216128	7492548	94	2	4	0.3	5	1	0	18	34	0	5.0	12
3009	216159	7492513	90	6	4	1.2	2	2	4	18	29	43	4.5	9
3010	220047	7494557	24	37	39	1.8	89	27	0	168	70	0	5.2	59
3011	220092	7494601	59	19	22	1.5	43	14	0	95	62	0	5.2	27
3012	215268	7491504	90	4	6	1.1	6	3	3	36	28	23	4.4	32
3013	215200	7491521	31	34	35	3.9	56	15	2	127	59	3	4.5	37
3014	218591	7493239	53	24	23	1.9	17	11	2	58	52	6	4.6	14
3015	216228	7491925	20	47	33	1.3	22	9	3	80	40	8	4.3	24
3016	220428	7493336	33	40	27	2.8	10	2	16	73	20	52	3.9	19
3017	218746	7493322	55	25	20	1.4	15	3	9	63	31	32	4.1	22
3018	217324	7494051	84	8	8	1.0	5	2	2	28	29	20	4.3	9
3021	219201	7494590	30	35	35	1.4	27	10	14	116	33	27	4.1	59
3024	215146	7491575	66	18	16	1.1	32	4	2	87	43	5	4.4	8
3026	214986	7492057	84	6	10	1.5	9	5	12	69	23	44	4.1	8
3027	214734	7492097	94	2	4	1.5	5	3	9	40	24	49	4.1	5
3028	216125	7491836	35	41	24	3.2	45	12	7	150	40	10	4.3	26
3029	216322	7492111	72	14	14	0.9	39	10	1	100	50	2	4.8	23
3030	215992	7492774	90	4	6	0.9	10	4	0	39	38	0	4.3	5

Table A.6 continued

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K^{+}**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C$_{org}$**
	m	**m**	**%**	**%**	**%**			**mmol$_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
3032	215814	7491831	92	2	6	0.7	3	2	10	46	12	64	4.1	5
3034	217675	7492635	18	23	59	6.8	89	23	16	279	43	12	4.6	51
3035	219243	7494482	26	38	36	11.3	94	25	0	190	68	0	5.2	33
3036	216262	7492489	94	4	2	1.0	5	2	4	32	25	33	4.2	0
3037	216091	7492694	88	4	8	1.5	12	5	5	52	36	21	4.3	8
3038	217556	7493632	100	0	0	4.7	120	24	1	239	62	1	5.0	59
3039	217515	7494335	25	35	40	2.3	29	16	49	277	17	51	3.9	56
3040	221134	7493249	25	38	37	11.6	78	24	1	174	65	1	4.8	26
3041	219323	7494322	11	43	46	3.2	69	23	12	195	49	11	5.0	43
3042	219861	7494423	21	33	46	1.7	99	24	11	236	53	8	5.0	61
3043	219983	7494474	36	31	33	1.4	39	19	11	175	34	16	4.5	36
3044	218265	7493684	3	38	59	2.6	67	22	3	222	41	3	4.7	56
3045	218572	7493110	13	31	56	1.4	112	23	1	186	73	1	5.0	46
3046	219087	7492522	35	39	26	1.0	24	8	3	85	39	8	4.5	22
3047	219087	7492522	25	35	40	2.5	51	8	2	110	56	3	4.6	19
4001	214645	7491993	69	11	20	1	29	9	18	79	49	32	4	10
4002	217166	7493673	90	6	4	0.1	7	1	4	18	45	33	4.1	5
4005	216112	7492041	80	12	8	1.5	28	7	0	53	70	0	5	15
4006	220234	7492829	70	18	12	5.2	24	7	0	53	68	0	5	10
4007	215273	7492671	88	6	6	0.8	24	6	0	47	66	0	4.9	20
4009	214714	7492245	82	4	14	0.9	8	2	19	53	21	64	3.9	15
4010	216457	7493658	86	6	8	2.2	7	5	1	27	52	7	4.7	10
4012	216879	7493065	42	21	37	3.5	63	35	0	132	77	0	5.5	28
4013	215907	7491444	43	31	26	2	27	17	4	76	61	8	4.3	18
4015	218103	7493138	29	40	31	4.7	27	15	1	89	53	2	4.5	26
4016	218330	7492925	31	38	31	1.6	39	14	3	91	60	5	4.5	23

Table A.6 continued

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C_{org}**
	m	**m**	**%**	**%**	**%**			**$mmol_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
4017	218912	7492529	18	24	58	15.8	48	27	0	121	75	0	4.2	15
4019	218568	7494902	56	16	28	4	8	4	8	46	35	33	4	13
4023	217882	7492926	53	29	18	1.8	22	9	8	65	51	20	4.2	15
4026	218109	7494173	56	30	14	2.3	11	5	7	55	33	28	4.1	15
4027	218619	7492037	63	21	16	6.7	42	18	3	85	79	4	4.4	18
4028	219254	7494199	51	25	24	3.7	24	10	5	91	42	12	4.4	23
4029	218694	7491833	55	18	27	15.9	99	24	0	165	84	0	5.7	26
5001	216293	7492949	78	8	14	3.8	20	5	1	64	45	3	4.8	15
5002	216271	7492926	73	11	16	1.9	14	3	0	51	37	0	4.5	19
5003	216251	7492904	80	6	14	1.1	9	2	3	47	26	20	4.6	10
5004	216231	7492882	76	10	14	1.7	10	3	5	56	26	25	4.3	26
5005	216211	7492860	80	12	8	3.8	6	3	10	37	35	44	4.1	8
5006	216193	7492838	82	6	12	1.8	7	3	8	36	33	40	3.9	10
5007	216173	7492815	84	4	12	1.2	6	3	8	29	35	44	4.2	8
5008	216151	7492793	84	8	8	2.9	5	2	10	36	28	50	3.9	8
5009	216131	7492771	78	10	12	1.4	5	2	18	47	18	68	3.8	13
5010	216111	7492749	80	8	12	1.2	7	2	7	40	25	41	3.9	10
5011	216100	7492735	76	10	14	0.7	11	4	8	56	28	34	3.9	10
5012	216317	7492930	68	14	18	2.3	21	5	6	58	49	17	4.4	15
5013	216297	7492909	74	12	14	3.5	21	7	0	64	50	0	4.9	29
5014	216277	7492886	82	10	8	1.9	9	4	6	39	38	29	4.4	24
5015	216257	7492864	78	8	14	2.2	9	4	15	54	28	50	4.1	24
5016	216237	7492842	78	10	12	2.0	12	3	5	45	38	23	4.2	28
5017	216217	7492820	74	10	16	1.1	15	5	22	57	37	51	3.7	26
5018	216197	7492798	82	12	6	1.1	6	2	10	32	28	52	3.6	31
5019	216177	7492776	82	8	10	0.9	11	3	2	37	40	12	4.8	34

Table A.6 continued

Sample	**Westing** m	**Southing** m	**Sand** %	**Silt** %	**Clay** %	**K^+**	**Ca^{2+}**	**Mg^{2+}** $mmol_c\ kg^{-1}$	**Al^{3+}**	**CEC**	**B. sat** %	**Al. sat** %	**pH**	**C_{org}** $g\ kg^{-1}$
5020	216157	7492754	84	10	6	0.7	9	3	8	43	30	39	4.2	8
5021	216137	7492732	82	10	8	1.4	8	1	9	40	26	46	4.1	13
5022	216125	7492719	84	8	8	0.6	7	5	11	45	28	47	4.1	10
5023	216321	7492891	76	12	12	2.6	27	3	0	81	40	0	4.8	18
5024	216301	7492869	82	10	8	1.2	11	4	2	52	31	11	4.2	13
5025	216282	7492846	61	12	27	0.4	10	3	43	83	16	76	4.0	8
5026	216263	7492824	78	8	14	1.7	20	5	3	69	39	10	4.4	13
5027	216242	7492802	74	12	14	1.4	13	3	13	69	25	43	4.1	10
5028	216367	7492895	62	16	22	1.6	37	7	0	90	51	0	4.8	18
5029	216346	7492874	82	8	10	0.8	11	2	1	52	27	7	4.4	8
5030	216326	7492851	82	8	10	1.1	7	1	2	47	19	18	4.0	5
5031	216306	7492830	82	8	10	0.9	8	1	3	38	26	23	4.1	8
5032	216287	7492808	88	6	6	1.2	6	1	5	32	25	38	4.0	8
5033	216267	7492785	82	10	8	0.5	12	6	3	43	44	14	4.5	5
5034	216247	7492763	80	10	10	1.9	16	3	6	59	35	22	4.2	15
5035	216227	7492741	82	4	14	1.4	20	3	3	60	40	11	4.4	5
5036	216207	7492719	84	8	8	1.8	8	1	7	53	20	39	4.2	8
5037	216187	7492696	86	6	8	1.4	3	1	14	53	10	72	3.8	5
5038	216167	7492674	80	8	12	2.4	7	2	15	63	18	57	4.0	3
5039	216391	7492891	49	12	39	1.9	52	13	0	98	68	0	4.7	10
5040	216371	7492869	45	16	39	4.8	41	12	0	105	55	0	5.0	18
5041	216351	7492846	70	12	18	2.1	19	6	0	57	47	0	4.9	5
5042	216333	7492823	80	10	10	1.6	10	2	5	53	26	27	4.2	8
5043	216313	7492801	80	8	12	1.4	9	3	3	39	34	18	4.2	5
5044	216295	7492780	80	10	10	1.5	8	2	7	52	22	38	3.9	10
5045	216276	7492760	80	12	8	2.6	9	5	17	67	25	51	3.9	18

Table A.6 continued

Sample	**Westing** m	**Southing** m	**Sand** %	**Silt** %	**Clay** %	**K$^+$**	**Ca^{2+}**	**Mg^{2+}** mmol$_c$ kg^{-1}	**Al^{3+}**	**CEC**	**B. sat** %	**Al. sat** %	**pH**	**C$_{org}$** g kg^{-1}
5046	216256	7492736	80	10	10	1.6	12	5	10	49	38	35	4.0	15
5047	216237	7492713	84	10	6	1.9	6	3	10	48	23	48	3.9	13
5048	216217	7492691	86	8	6	1.5	7	3	5	39	30	30	4.0	13
5049	216197	7492669	82	8	10	0.8	4	1	10	38	15	63	4.0	13
5050	216177	7492645	94	2	4	0.6	3	1	0	17	28	0	4.3	5
5051	216358	7492816	76	10	14	0.9	12	3	1	36	44	6	4.6	5
5052	216339	7492794	80	8	12	1.7	11	3	9	49	32	36	4.3	10
5053	216320	7492771	82	8	10	1.8	14	3	2	59	32	10	4.4	13
5054	216301	7492748	84	8	8	2.1	8	3	11	54	24	46	3.9	10
5055	216283	7492724	82	10	8	0.9	8	2	11	54	20	50	4.0	10
5056	216264	7492701	76	14	10	1.9	11	3	11	59	27	41	4.0	10
5057	216245	7492678	86	8	6	0.9	5	2	9	37	21	53	4.1	5
5058	216226	7492654	84	6	10	1.3	3	2	12	46	14	66	3.8	5
5070	216119	7493176	82	12	6	1.7	7	1	6	58	17	38	4.3	9
5071	216072	7493113	70	12	18	1.1	60	30	0	113	81	0	5.1	14
5072	215953	7493034	76	8	16	5.9	12	5	19	79	29	45	4.1	10
5073	215873	7493276	86	8	6	2.1	8	2	4	32	38	25	4.4	9
5074	215867	7493219	72	16	12	3.8	22	11	11	89	41	23	4.3	10
5075	215876	7493079	80	12	8	4.4	10	4	11	98	19	37	4.0	8
5076	215876	7493079	88	6	6	2.1	3	2	6	113	6	46	4.1	36
5077	215494	7493032	80	8	12	2.8	8	4	15	95	16	50	4.1	38
5078	215682	7493020	82	6	12	6.4	2	2	8	60	17	43	4.0	36
5079	215744	7492838	92	4	4	2.9	2	1	3	36	16	34	4.2	36
5080	215783	7492873	94	4	2	0.6	2	2	3	33	14	39	4.2	33
5081	215851	7492882	84	6	10	1.1	14	5	4	60	33	17	4.3	41
5082	215844	7492536	84	10	6	2.4	5	2	3	31	30	24	4.4	5

Table A.6 continued

Sample	**Westing**	**Southing**	**Sand**	**Silt**	**Clay**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**CEC**	**B. sat**	**Al. sat**	**pH**	**C_{org}**
	m	**m**	**%**	**%**	**%**			**$mmol_c$ kg^{-1}**			**%**	**%**		**g kg^{-1}**
5083	215929	7492571	61	10	29	0.3	20	7	24	74	37	47	4.2	5
5084	216021	7492635	82	8	10	1.4	12	7	0	34	59	0	5.4	8
5085	216050	7492451	80	6	14	1.8	20	13	0	55	64	0	6.9	5
5086	216095	7492512	84	10	6	2.6	3	2	4	34	23	34	4.1	5
5087	216134	7492508	82	8	10	0.7	6	2	8	43	20	48	3.8	5
5088	216199	7492344	76	14	10	0.5	6	3	4	30	32	30	4.3	5
5089	216241	7492363	70	16	14	1.3	9	3	8	44	30	38	3.9	15
6001	216008	7493029	69	15	16	2.3	26	13	17	77	53	29	4.2	10
6002	215959	7493120	71	15	14	1.7	28	16	4	81	57	8	4.4	26
6003	216062	7493134	82	10	8	5.3	23	12	1	71	57	2	4.6	28
6004	215880	7492938	84	6	10	0.8	4	3	8	26	30	51	4.0	10
6005	217315	7495059	78	10	12	0.8	1	1	7	23	12	71	3.7	8
6006	217234	7495022	75	11	14	0.8	9	4	3	40	35	18	4.1	33
6007	217274	7495098	84	8	8	0.7	5	3	5	25	35	36	3.7	10
6008	217382	7494709	82	4	14	0.7	25	5	3	55	56	9	4.5	31
6009	218824	7495378	57	16	27	1.2	23	11	5	59	59	12	3.9	18
6010	218580	7495423	80	8	12	0.4	1	1	8	15	16	77	3.7	5
6011	218916	7495525	64	19	17	3.4	29	7	3	76	52	7	4.4	18
6012	219054	7495431	17	45	38	3.9	53	10	1	83	81	1	4.7	20
6013	218958	7495420	57	21	22	1.7	17	7	0	44	59	0	5.0	5
6014	219316	7493831	28	45	27	1.0	38	8	1	65	72	2	4.8	15
6015	219350	7493778	47	28	25	1.8	74	20	0	122	79	0	5.0	28
6016	219256	7492682	19	33	48	11.5	69	31	0	122	92	0	5.2	23
6017	219298	7492634	63	15	22	1.8	89	22	0	123	92	0	6.0	31
6018	219128	7492660	23	42	35	3.0	112	38	1	186	82	1	5.1	8
6019	219350	7492658	45	35	20	1.6	39	13	2	82	66	4	4.5	23

Table A.6 continued

Sample	**Westing** **m**	**Southing** **m**	**Sand** **%**	**Silt** **%**	**Clay** **%**	**K^+**	**Ca^{2+}**	**Mg^{2+}** **$mmol_c\ kg^{-1}$**	**Al^{3+}**	**CEC**	**B. sat** **%**	**Al. sat** **%**	**pH**	**C_{org}** **$g\ kg^{-1}$**
6020	220016	7492671	63	10	27	4.5	59	12	3	112	68	4	4.7	10
6021	219964	7492528	32	45	23	4.3	255	28	0	297	97	0	5.8	10
6022	220038	7492607	71	19	10	4.3	41	13	3	78	74	5	4.5	28
6023	219479	7492399	29	35	36	7.4	64	28	3	130	76	3	4.4	20
6024	219538	7492316	24	43	33	4.2	55	17	3	122	62	4	4.2	36
6025	219584	7492234	38	39	23	7.1	20	21	2	92	52	4	5.2	31
6026	219416	7492344	28	45	27	3.8	58	15	3	121	64	4	4.0	31
6027	219442	7492223	26	40	34	8.1	101	31	1	164	85	1	4.8	43
6028	215635	7491199	31	42	27	2.6	89	17	3	173	63	3	4.8	23
6029	215645	7491291	42	27	31	4.7	95	26	3	182	69	2	4.9	43
6030	215611	7491348	23	42	35	1.3	105	28	2	202	66	1	5.2	43
6031	215556	7491347	65	19	16	2.6	73	19	1	133	71	1	5.6	23

Table A.6 continued

Sample	**AR-P mg kg^{-1}**	**WH-P mg kg^{-1}**	**AAC-P mg kg^{-1}**	**Resin-P mg kg^{-1}**	**$CaCl_2$-P mg kg^{-1}**	**Fe g kg^{-1}**	**Zn mg kg^{-1}**
1001	82.6	22.3	7.05	8	<0.01	0.51	5.70
1002	59	0.01	1.02	2	<0.01	0.64	7.75
1003	24.3	0.01	0.13	1	<0.01	1.20	11.8
1004	47.6	0.01	0.13	4	<0.01	1.58	19.1
1005	63.5	2.74	1.22	4	<0.01	2.23	27.5
1006	182	8.64	3.72	14	<0.01	1.13	22.4
1007	74.2	1.69	1.28	5	<0.01	1.09	19.5
1008	78.5	6.42	2.50	2	<0.01	0.44	7.12
1009	150	0.21	3.20	6	<0.01	1.64	18.6
1010	176	2.32	0.96	7	<0.01	1.35	20.6
1011	127	3.37	1.02	5	<0.01	2.05	38.8
1012	45	16.2	5.07	6	<0.01	0.36	2.16
1015	15.1	4.21	1.57	2	<0.01	0.34	5.47
1016	16.7	2.18	1.16	2	<0.01	0.32	5.37
1017	65.8	1.64	0.83	3	<0.01	0.87	10.5
1018	33.5	1.2	0.58	3	<0.01	1.21	4.49
1019	104	19.2	4.87	14	<0.01	0.60	8.66
1020	130	115	47.1	22	0.12	0.53	5.51
1021	40	5.34	2.06	3	< 0.01	0.60	5.23
1022	163	4.58	3.72	6	< 0.01	1.44	20.7
1023	388	90.3	38.5	17	0.62	2.38	40.9
1024	130	3.6	1.99	3	< 0.01	0.57	17.6
1025	277	6.32	3.78	14	< 0.01	2.33	34.2
1026	101	14.9	6.55	4	< 0.01	0.71	8.53
1027	575	28.9	7.44	53	0.02	2.91	65.1
1028	338	10	5.26	36	0.03	2.37	36.9
1029	153	4.25	1.47	13	< 0.01	1.64	19.3
1030	170		1.93	3	< 0.01	1.43	20.9
1031	249	4.05	1.28	14	< 0.01	2.33	31.6
1032	283	27.6	8.54	13	< 0.01	2.86	42.3
1033	834	43.2	28.7	62	0.03	2.73	59.7
1034	591	168	38.1	50	0.32	2.56	43.7
1036	238	10.5	6.34	9	< 0.01	4.52	44.2
1037	126	52.8	16.5	26	< 0.01	2.03	34.2
1038	245	16.6	5.37	26	< 0.01	2.15	49.7
1039	149	9.16	4.21	8	< 0.01	1.28	18.5
1040	235	12.6	3.72	10	< 0.01	2.69	50.4
1041	234	1.2	0.85	3	< 0.01	1.52	33.4
1042	378	36.8	9.76	26	< 0.01	2.64	31.6
1043	193	9.05	2.67	3	< 0.01	2.63	45.7
1044	581	168	67.2	88	0.89	2.40	53.8
1045	200	6.21	1.65	7	< 0.01	2.86	50.3
1046	577	127	22.6	54	0.02	3.39	68.4
1048	348	2.07	1.28	6	< 0.01	4.58	58.3
1049	461	51.2	21.6	59	< 0.01	3.43	48.8
1050	218	2.62	2.62	6	< 0.01	3.93	55.8
1051	237	106	21.3	28	0.26	0.77	10.5
1052	51.6	4.36	2.20	4	< 0.01	0.47	8.48

Table A.6 continued

Sample	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**Resin-P** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
1053	114	12	4.94	6	< 0.01	0.32	13.3
1054	46	11	3.17	6	< 0.01	0.45	6.79
1055	35.7	9.6	2.61	3	< 0.01	0.38	7.64
1056	357	2.27	1.65	10	< 0.01	11.63	97.8
1057	105	1.94	0.98	3	< 0.01	2.75	31.5
1058	53.4	0.65	0.55	3	< 0.01	2.41	38.0
1059	308	4.99	2.32	5	< 0.01	3.79	57.9
1060	299	36.7	6.40	10	< 0.01	2.11	56.7
1061	456	28.7	69.8	85	0.88	1.89	63.1
1062	73	2.49	1.16	6	< 0.01	0.95	14.8
1063	144	0.65	0.49	4	< 0.01	2.38	25.9
1064	536	0.43	0.37	4	< 0.01	3.03	94.9
1065	182	0.87	0.55	4	< 0.01	2.08	58.5
1066	928	239	69.5	92	0.61	5.73	56.5
1067	553	220	29.3	68	0.81	2.51	74.3
1068	403	48.8	10.1	22	< 0.01	3.34	70.8
1069	878	105	10.4	41	0.11	3.58	70.2
1070	223	3.25	1.95	6	< 0.01	2.19	25.5
1071	782	6.29	1.10	4	< 0.01	2.64	71.1
1072	115	131	32.6	13	< 0.01	0.33	6.97
1073	117	15	6.40	7	< 0.01	0.31	7.24
1074	321	107	40.1	31	0.86	0.76	17.3
1075	35	3.47	2.07	2	< 0.01	0.33	5.55
1076	626	11.7	1.04	6	< 0.01	8.97	132
1077	249	0.85	1.04	3	< 0.01	3.39	60.5
1078	150	11.6	11.0	8	< 0.01	0.35	7.21
1079	73.2	11	9.31	12	< 0.01	0.27	6.52
1080	94.7	1.28	1.93	6	< 0.01	0.97	16.0
1081	198	1.38	1.52	8	< 0.01	2.46	29.2
1082	430	234	13.9	58	0.76	2.14	75.2
1083	213	4.89	2.69	33	< 0.01	2.75	45.8
1084	247	1.6	2.48	5	< 0.01	2.39	41.7
1085	268	10.2	2.69	4	< 0.01	1.82	48.3
1086	200	3.19	4.29	5	< 0.01	1.40	32.9
1087	106	2.45	1.17	3	< 0.01	2.28	47.1
1088	123	2.98	1.45	4	< 0.01	1.30	23.6
1089	171	147	14.4	27	0.84	0.29	10.9
1090	71.5	11.3	3.51	6	< 0.01	0.47	13.2
1091	330	3.83	2.83	14	< 0.01	2.87	43.7
1092	33.3	1.17	1.45	2	< 0.01	0.72	5.03
1093	47.6	12.1	9.81	14	< 0.01	0.27	6.60
1094	165	1.81	3.25	3	< 0.01	1.97	28.8
1095	197	0.53	1.59	5	< 0.01	1.43	24.9
1096	158	17.3	8.92	9	< 0.01	1.05	43.8
1097	330	18.3	8.77	14	< 0.01	2.64	40.4
1098	472	44	12.5	27	< 0.01	2.35	57.6
1099	195	1.31	1.65	6	< 0.01	3.05	28.7
1113	147	51	10.4	17	< 0.01	0.00	72.9

Table A.6 continued

Sample	AR-P mg kg^{-1}	WH-P mg kg^{-1}	AAC-P mg kg^{-1}	Resin-P mg kg^{-1}	$CaCl_2$-P mg kg^{-1}	Fe g kg^{-1}	Zn mg kg^{-1}
1114	649	1.51	n.a.	4	< 0.01	7.60	n.a.
1115	259	50.4	17.5	21	< 0.01	1.53	34.9
1116	163	36.8	3.31	6	< 0.01	1.33	24.5
1117	389	35.5	3.31	4	< 0.01	1.96	49.2
1118	697	17.7	3.17	5	< 0.01	3.13	76.5
1119	266	6.54	6.70	5	< 0.01	1.90	46.8
1120	833	277	166	114	2.15	0.84	32.1
1121	167	27.7	13.8	13	< 0.01	0.78	25.6
1122	32.5	4.58	2.27	9	< 0.01	0.16	4.74
1123	41.6	6.98	3.52	4	< 0.01	0.22	7.04
1124	111	7.96	3.44	5	< 0.01	1.55	35.4
1125	409	25.5	5.24	7	< 0.01	1.98	56.5
1126	162	1.05	0.55	5	0.06	1.81	n.a.
1127	140	0.76	0.96	2	< 0.01	1.93	29.0
1128	130	4.25	5.25	6	< 0.01	0.74	19.1
1129	196	2.94	2.27	7	< 0.01	2.27	38.9
1130	191	5.01	2.00	7	< 0.01	2.30	47.5
1131	195	33.1	6.55	12	< 0.01	1.95	53.0
1132	204	6.43	2.20	9	< 0.01	1.59	27.0
2013	247	135	57.6	43	2.94	0.37	27.1
2014	619	81.5	29.3	76	0.21	2.56	n.a.
2015	477	28.3	9.95	24	< 0.01	2.37	45.7
2016	263	22.8	8.29	24	< 0.01	1.93	28.3
2017	512	57	33.3	51	< 0.01	3.19	68.2
2018	518	47	16.7	33	0.13	1.79	48.5
2019	247	18.9	7.77	8	< 0.01	1.78	32.3
2020	280	4.19	2.82	4	0.39	2.52	49.0
2021	432	97.1	n.a.	44	< 0.01	3.90	72.7
2022	54.1	3.11	1.60	1	< 0.01	0.48	9.03
2023	188	0.43	1.09	3	< 0.01	1.85	26.0
2024	103	7.62	2.88	1	< 0.01	0.66	16.1
2025	30.4	4.19	2.12	1	0.07	0.27	n.a.
2026	76.2	5.69	2.57	5	< 0.01	0.41	6.00
2027	217	15.1	2.95	20	0.07	1.63	28.7
2029	94.5	1.05	1.54	12	< 0.01	1.63	22.4
2030	81.1	4.89	2.33	12	0.07	1.13	n.a.
3001	317	71.7	13.3	20	< 0.01	1.58	51.7
3002	204	16.8	8.42	8	< 0.01	1.22	28.6
3003	750	405	n.a.	115	0.23	1.44	n.a.
3004	n.a.	11.8	3.66	6	< 0.01	0.00	n.a.
3005	193	9.67	3.30	6	< 0.01	1.44	26.1
3006	126	2.58	1.34	2	< 0.01	1.30	20.8
3007	120	8.59	2.81	4	< 0.01	0.76	12.8
3008	38.2	2.26	1.10	3	< 0.01	0.72	4.62
3009	37	6.66	2.44	4	< 0.01	0.42	4.96
3010	581	13.3	4.27	29	< 0.01	4.46	64.5
3011	335	13.3	3.48	10	< 0.01	2.94	50.5
3012	53.9	3.76	1.95	3	< 0.01	0.52	5.91

Table A.6 continued

Sample	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**Resin-P** **mg kg^{-1}**	**CaCl$_2$-P** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
3013	169	3.11	1.34	4	< 0.01	1.60	33.2
3014	174	2.68	1.22	4	< 0.01	1.51	20.7
3015	221	5.8	2.56	6	< 0.01	2.07	43.5
3016	247	8.81	2.50	7	< 0.01	1.73	25.8
3017	239	12.1	4.57	11	< 0.01	1.31	20.4
3018	41.6	5.58	1.83	4	< 0.01	0.57	5.09
3019	13.1	2.79	1.16	n.a.	< 0.01	0.39	1.91
3020	1117	177	41.1	n.a.	0.11	5.71	92.8
3021	482	43.2	11.7	13	< 0.01	2.67	68.6
3022	293	6.69	2.56	n.a.	< 0.01	1.34	51.7
3024	125	3.67	1.77	2	< 0.01	1.05	17.7
3025	233	10.4	3.79	n.a.	< 0.01	0.99	25.1
3026	147	12.3	2.56	3	< 0.01	0.92	12.7
3027	49.1	6.48	1.10	4	< 0.01	0.56	4.2
3028	295	27.6	5.62	11	0.02	2.05	29.4
3029	200	4.53	1.28	5	< 0.01	1.15	22.2
3030	65.4	2.27	0.73	3	< 0.01	0.55	4.45
3032	151	6.37	2.01	2	< 0.01	0.86	11.8
3034	779	64.5	11.6	30	0.01	2.24	68.9
3035	639	141	40.7	58	0.07	3.24	77.6
3036	87.4	2.7	0.97	3	< 0.01	0.64	6.31
3037	66.2	3.99	1.16	3	< 0.01	0.74	8.34
3039	1000	179	48.9	61	0.07	1.96	55.3
3040	633	62.6	14.8	36	0.03	2.41	60.2
3041	747	29.5	7.01	25	< 0.01	3.43	83.8
3042	1041	82	10.1	51	0.07	3.67	84.1
3043	735	112	14.0	28	< 0.01	3.17	58.5
3044	620	16.5	3.85	25	< 0.01	3.65	82.3
3045	64.9	32.6	8.84	31	0.11	0.00	4.14
3046	403	5.07	3.11	7	< 0.01	2.11	34.5
3047	405	0.86	1.10	3	< 0.01	3.53	41.7
4001	77.7	0.86	0.49	2	< 0.01	0.60	11.1
4002	64.7	27.2	9.58	8	< 0.01	0.17	4.18
4005	207	134	47.5	104	5.07	0.44	9.06
4006	227	21.7	9.89	43	0.03	0.08	35.4
4007	285	248	105	136	8.90	0.19	7.78
4009	72.8	5.75	1.83	3	< 0.01	0.48	6.57
4010	72.9	3.25	1.46	3	< 0.01	0.65	12.1
4012	795	7.81	1.89	29	< 0.01	9.47	148
4013	191	3.25	1.83	4	< 0.01	2.78	30.3
4015	577	41.4	15.5	39	0.03	1.77	46.6
4016	341	1.52	1.22	15	< 0.01	2.58	35.2
4017	494	0.98	0.21	4	< 0.01	3.50	58.8
4019	451	0.33	0.43	3	< 0.01	3.84	53.4
4023	126	3.9	2.14	4	< 0.01	1.11	20.3
4026	144		2.56	2	< 0.01	1.72	27.7
4027	123	0.76	1.59	6	< 0.01	1.34	25.6
4029	834	383	146	230	1.25	1.64	41.5

Table A.6 continued

Sample	**AR-P** mg kg^{-1}	**WH-P** mg kg^{-1}	**AAC-P** mg kg^{-1}	**Resin-P** mg kg^{-1}	**CaCl$_2$-P** mg kg^{-1}	**Fe** g kg^{-1}	**Zn** mg kg^{-1}
5001	237	81.8	32.2	36	0.74	1.07	32.0
5002	111	1.09	1.24	5	< 0.01	1.42	27.9
5003	243	67.3	18.6	6	< 0.01	0.91	25.7
5004	59.7	1.75	1.45	2	< 0.01	0.75	11.1
5005	49.5	4.05	3.26	4	< 0.01	0.54	13.1
5006	70.9	9.53	4.62	5	< 0.01	n.a.	18.7
5007	45	3.62	1.03	3	< 0.01	0.77	33.9
5008	59.3	8.33	3.25	4	< 0.01	0.29	40.4
5009	142	33.3	14.6	7	< 0.01	0.34	10.5
5010	36.5	6.46	2.42	3	< 0.01	0.23	18.5
5011	31.2	5.59	2.82	4	< 0.01	0.42	8.20
5012	228	6.13	4.49	18	< 0.01	3.42	79.5
5013	222	12.1	7.18	7	< 0.01	2.58	65.6
5014	46.7	1.31	0.90	4	< 0.01	0.98	22.5
5015	168	4.16	1.94	4	< 0.01	1.06	12.5
5016	36	1.1	10.4	3	< 0.01	0.83	16.0
5017	20	0.88	0.21	2	< 0.01	1.07	16.0
5018	73.3	3.51	2.24	4	< 0.01	0.63	13.0
5019	79.7	9.31	4.48	4	< 0.01	0.58	24.6
5020	54.2	0.55	0.55	3	< 0.01	1.52	8.48
5021	45.4	6.03	1.93	6	< 0.01	0.48	9.95
5022	44.5	4.16	1.31	3	< 0.01	0.67	8.57
5023	267	17.1	8.99	13	< 0.01	2.66	62.9
5024	162	17.2	2.89	4	< 0.01	1.05	19.6
5025	42	0.22	0.28	2	< 0.01	1.52	15.9
5026	65.1	2.41	2.56	5	< 0.01	1.20	30.7
5027	30.5	0.55	0.90	4	< 0.01	0.97	57.0
5028	233	0.33	0.55	5	< 0.01	5.22	107
5029	67.6	1.53	1.17	6	< 0.01	1.64	25.4
5030	78.3	14.2	5.60	7	< 0.01	1.10	13.1
5031	77.1	6.57	3.53	5	< 0.01	0.93	10.6
5032	52.9	2.63	1.80	5	< 0.01	0.78	9.34
5033	26.2	9.75	0.27	3	< 0.01	0.83	10.1
5034	63.2	9.86	1.38	4	< 0.01	0.81	13.9
5035	31.4	0.66	0.55	3	< 0.01	1.18	14.6
5036	41.5	2.74	1.71	4	< 0.01	0.57	7.68
5037	28.1	8.44	3.59	4	< 0.01	0.61	4.39
5038	30.1	7.45	2.07	5	< 0.01	0.91	10.5
5039	353	6.13	2.56	11	< 0.01	6.23	96.0
5040	428	0.22	0.06	6	< 0.01	8.91	145
5041	154	0.11	0.06	4	< 0.01	3.65	46.6
5042	86.7	1.31	0.67	5	< 0.01	1.77	25.8
5043	24.5	0.66	0.37	3	< 0.01	1.21	17.1
5044	106	23.4	4.21	10	0.10	1.09	17.3
5045	61.1	3.29	1.52	2	< 0.01	1.10	25.4
5046	77.2	5.92	1.65	3	< 0.01	1.00	21.5
5047	37.3	5.59	1.71	2	< 0.01	0.81	9.28
5048	59.1	7.56	2.01	3	< 0.01	0.66	7.50

Table A.6 continued

Sample	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**Resin-P** **mg kg^{-1}**	**CaCl$_2$-P** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
5049	92.4	25	5.51	4	< 0.01	0.92	8.87
5050	37.2	2.63	0.67	2	< 0.01	0.97	16.6
5051	72.6	0.44	0.31	3	< 0.01	2.07	23.6
5052	54	0.22	1.27	1	< 0.01	2.28	18.4
5053	52.7	4.93	0.18	3	< 0.01	0.95	9.84
5054	63.5	9.86	2.38	3	< 0.01	0.47	8.91
5055	59.4	3.83	1.22	3	< 0.01	0.46	9.64
5056	78.7	3.07	1.28	3	< 0.01	0.57	18.1
5057	38.1	21.5	1.58	2	< 0.01	0.30	5.61
5058	33.2	2.85	1.32	3	< 0.01	0.42	7.38
5070	95.3	42.9	9.30	8	< 0.01	0.40	7.37
5071	64.9	4.82	1.46	3	< 0.01	0.76	13.5
5072	53.5	1.21	0.90	4	< 0.01	1.60	17.1
5073	83.4	39.9	11.4	13	< 0.01	0.22	20.0
5074	76.2	3.29	1.83	3	< 0.01	0.51	16.1
5075	44.4	3.51	1.28	3	< 0.01	0.37	4.38
5076	20.7	0.99	0.79	2	< 0.01	0.52	24.9
5077	57.2	6.98	2.08	4	< 0.01	0.45	27.0
5078	22.8	2.98	1.10	2	< 0.01	0.34	3.92
5079	21.8	5.13	1.94	3	< 0.01	0.24	6.23
5080	20.3	4	6.53	2	< 0.01	0.25	2.12
5081	150	68.6	15.6	9	< 0.01	0.71	9.98
5082	30	3.59	0.85	1	< 0.01	0.49	8.57
5083	109	13	2.44	1	< 0.01	0.84	15.8
5084	49.5	3.29	1.71	2	< 0.01	0.53	12.7
5085	59.1	8.21	3.23	4	< 0.01	0.54	5.11
5086	45.3	7.8	1.47	2	< 0.01	0.30	3.61
5087	51.5	4.11	1.71	2	< 0.01	0.42	15.4
5088	59.6	3.08	0.79	1	< 0.01	0.70	8.70
5089	70.1	3.59	1.10	3	< 0.01	1.01	14.5
6001	85.7	5.42	2.56	5	< 0.01	0.68	7.83
6002	110	9.13	n.a.	5	< 0.01	0.70	13.5
6003	84.6	3.58	5.00	6	< 0.01	0.51	12.8
6004	30.2	3.8	2.16	3	< 0.01	0.37	4.85
6005	46.1	5.21	2.63	2	< 0.01	0.18	4.00
6006	53.1	7.7	2.75	4	< 0.01	0.33	7.38
6007	62.5	2.82	2.18	2	< 0.01	0.33	4.53
6008	84.8	5.53	7.94	5	< 0.01	0.49	7.81
6009	118	1.74	2.44	3	< 0.01	1.43	20.0
6010	30.8	1.52	1.59	2	< 0.01	0.38	4.15
6011	171	4.34	2.74	14	< 0.01	1.75	53.7
6012	240	8.03	3.42	4	< 0.01	2.22	65.4
6013	140	14.5	5.36	5	< 0.01	1.41	40.6
6014	280	13	9.69	24	< 0.01	1.50	33.9
6015	225	20.4	7.97	20	< 0.01	2.06	31.5
6016	246	4.45	2.44	14	< 0.01	2.50	61.9
6017	166	16.5	12.6	21	< 0.01	1.10	44.0
6018	388	31.7	6.35	32	0.13	1.66	56.4

Table A.6 continued

Sample	**AR-P** **mg kg^{-1}**	**WH-P** **mg kg^{-1}**	**AAC-P** **mg kg^{-1}**	**Resin-P** **mg kg^{-1}**	**$CaCl_2$-P** **mg kg^{-1}**	**Fe** **g kg^{-1}**	**Zn** **mg kg^{-1}**
6019	254	1.52	1.71	8	< 0.01	2.82	32.0
6020	154	20	0.93	6	< 0.01	1.41	23.1
6021	486	18.9	16.2	33	0.61	4.34	n.a.
6022	201	41.2	13.7	20	< 0.01	0.99	25.0
6023	301	3.04	1.89	11	< 0.01	2.72	43.8
6024	235	0.87	3.48	10	< 0.01	1.59	39.1
6025	296	4.23	3.17	6	< 0.01	1.96	42.0
6026	206	0.98	2.25	9	< 0.01	1.78	34.3
6027	254	41	8.84	18	< 0.01	1.29	44.4
6028	215	3.15	1.71	3	< 0.01	1.83	49.9
6029	221	1.84	3.04	6	< 0.01	1.58	53.4
6030	306	8.89	10.5	20	< 0.01	1.99	39.8
6031	148	18.5	7.33	15	< 0.01	0.99	19.5

n.a. = not analysed/not available

Tab. A.7: Calculated and extracted terrain attributes, fertiliser rates and soil texture classes for sampling points at Kassow (E12º06', N53º 10').

Sample	Soil	Fertilisation mg ha^{-1} P_2O_5	Elevation m	Slope º	PLC	PRC	LS	ω
1	Sl3	n.a.	27.0	0.9	0.20	-0.25	0.22	5.94
2	Sl3	6.51	25.4	2.0	0.25	-0.06	0.54	5.99
4	lS3	4.54	24.6	1.9	0.12	0.06	0.33	6.10
5	lS3	8.02	23.5	1.8	0.16	-0.19	0.32	6.14
6	lS3	9.40	23.4	2.8	0.17	-0.09	0.31	6.19
7	lS3	6.07	23.3	2.7	0.10	-0.11	0.34	6.20
8	lS3	2.65	22.7	2.3	0.07	-0.04	0.35	6.27
9	lS3	5.00	22.5	2.1	0.04	-0.20	0.31	6.27
10	lS3	12.7	23.1	2.8	0.06	-0.02	0.30	6.32
11	lS3	17.5	22.0	3.9	0.11	-0.01	0.27	6.41
12	lS3	12.1	21.0	4.0	0.09	-0.19	0.12	6.51
13	lS3	2.19	19.0	3.1	0.29	-0.05	0.12	6.57
14	lS3	21.5	19.3	1.4	0.06	-0.07	0.22	6.62
15	lS3	10.8	21.2	3.3	0.13	0.13	0.40	6.63
16	lS3	19.3	24.2	3.4	-0.01	0.03	0.48	6.67
17	Sl3	24.8	25.3	1.1	0.10	-0.03	0.80	6.68
19	lS3	13.5	25.7	2.3	0.07	0.11	0.58	6.69
20	Sl3	2.36	25.5	2.6	0.01	0.01	0.40	6.70
22	Sl3	11.3	27.3	3.7	0.05	-0.05	0.40	6.70
23	lS3	14.2	26.5	4.2	-0.02	0.19	0.53	6.73
24	lS3	8.22	25.7	1.4	0.02	-0.13	0.22	6.76
26	Sl3	5.92	26.3	1.7	0.07	-0.05	0.23	6.76
27	Sl3	11.3	26.1	0.6	-0.06	0.12	0.11	6.77
28	Sl3	15.4	27.1	1.6	0.06	-0.06	0.20	6.78
29	lS3	11.8	26.9	0.8	0.09	-0.04	0.39	6.78
30	lS3	13.0	26.3	0.6	0.08	-0.03	0.24	6.81
31	lS3	22.0	27.8	3.1	0.06	0.00	0.19	6.82
32	Sl3	22.8	29.1	0.4	0.07	-0.17	0.12	6.87
33	Sl3	19.3	28.5	1.5	0.11	-0.09	0.16	6.87
34	Sl3	15.4	27.2	1.3	0.03	-0.08	0.27	6.87
35	lS3	21.1	27.3	1.1	0.14	-0.06	0.11	6.88
36	lS3	34.4	26.2	1.2	0.06	-0.06	0.25	6.89
37	lS3	38.3	25.6	1.5	0.17	0.02	0.21	6.90
38	Sl3	36.1	24.2	2.1	0.05	0.03	0.44	6.93
39	lS3	34.7	22.4	2.0	0.12	-0.03	0.25	6.94
40	SL2	40.8	20.6	2.2	0.11	-0.03	0.45	6.95
41	SL2	46.0	20.4	2.4	0.01	-0.06	0.28	6.96
42	SL2	45.1	23.1	3.1	-0.04	-0.04	0.16	6.96
43	Sl3	42.1	24.6	2.7	0.00	-0.07	0.12	6.98
44	Sl3	42.9	24.8	0.8	-0.02	0.06	0.39	6.98
45	SL2	45.5	25.7	1.4	0.02	-0.12	0.18	7.00
46	SL2	40.8	27.0	2.1	-0.02	0.09	0.50	7.01
47	lS3	31.5	28.2	0.4	0.07	-0.01	0.21	7.02
48	lS3	28.6	28.1	0.9	0.03	0.02	0.35	7.04
49	Sl3	30.7	28.4	0.6	-0.04	0.04	0.37	7.04
50	Sl3	34.4	28.3	1.3	0.06	-0.05	0.34	7.05
51	lS3	40.2	27.6	0.7	0.00	-0.05	0.15	7.06
52	lS3	34.2	27.2	1.4	0.05	-0.02	0.17	7.07

Table A.7 continued

Sample	**Soil**	**Fertilisation mg ha^{-1} P$_2$O$_5$**	**Elevation m**	**Slope °**	**PLC**	**PRC**	**LS**	**ω**
53	Sl3	28.6	27.6	1.7	0.15	0.00	0.14	7.07
54	lS3	36.0	28.3	0.7	0.08	-0.04	0.20	7.09
55	lS3	41.8	27.8	0.2	0.05	0.05	0.10	7.09
56	lS3	44.4	27.5	0.2	0.00	-0.03	0.11	7.12
58	lS3	38.8	29.2	1.1	0.05	-0.04	0.23	7.12
59	lS3	39.6	29.1	1.5	-0.03	-0.03	0.16	7.14
60	lS3	39.6	28.3	0.3	0.02	0.15	0.51	7.18
61	SL2	43.3	27.5	1.6	-0.03	-0.11	0.14	7.20
62	SL2	44.9	25.9	1.6	0.03	0.12	0.66	7.22
63	lS3	45.9	25.3	0.8	0.06	0.03	0.31	7.23
64	lS3	46.5	25.0	1.1	0.03	0.10	0.28	7.24
65	lS3	48.5	23.5	2.8	-0.03	-0.03	0.20	7.25
66	lS3	55.6	21.6	3.3	-0.01	0.01	0.36	7.25
67	SL2	61.6	19.9	1.3	-0.06	0.02	0.44	7.28
68	SL2	62.2	22.7	3.6	0.01	-0.01	0.24	7.28
69	SL2	53.0	24.8	3.5	0.06	-0.04	0.11	7.28
70	lS3	46.9	26.0	1.1	0.01	0.17	0.55	7.30
71	lS3	46.8	26.2	0.9	0.00	-0.07	0.19	7.32
72	lS3	49.4	26.5	1.1	0.03	0.06	0.37	7.39
73	Sl3	47.9	27.8	1.5	-0.03	-0.05	0.16	7.39
74	Sl3	46.3	28.7	1.4	0.03	-0.02	0.10	7.40
75	lS3	45.4	29.8	1.6	0.00	0.07	0.41	7.40
76	lS3	43.4	30.4	1.5	0.07	0.00	0.37	7.41
77	lS3	43.3	29.6	2.6	-0.03	-0.12	0.15	7.43
78	lS3	43.3	28.4	2.6	0.09	0.00	0.08	7.44
79	lS3	41.4	28.3	1.5	0.01	-0.04	0.11	7.45
80	lS3	43.4	29.7	2.3	0.12	-0.09	0.08	7.46
81	lS3	45.2	31.0	2.1	0.01	0.01	0.21	7.46
82	lS3	45.4	31.5	1.6	0.06	0.01	0.20	7.47
83	lS3	46.2	31.7	0.7	-0.01	0.01	0.26	7.47
84	lS3	46.8	31.1	1.6	-0.03	0.03	0.18	7.48
85	lS3	46.6	29.6	2.1	0.04	-0.03	0.24	7.48
86	lS3	55.3	28.0	2.3	0.03	0.00	0.15	7.51
87	lS3	57.3	26.7	1.6	-0.02	0.05	0.21	7.55
88	lS3	51.9	25.8	1.9	-0.06	0.01	0.31	7.55
89	SL2	49.6	24.7	2.4	0.00	-0.10	0.22	7.55
90	SL2	54.1	22.6	3.2	0.03	-0.03	0.27	7.55
91	SL2	61.6	21.1	2.6	0.02	-0.02	0.12	7.56
92	sL3	69.9	19.7	1.7	-0.04	0.08	0.56	7.59
93	sL3	68.4	18.6	0.7	0.05	0.02	0.20	7.61
94	sL3	67.7	18.1	1.3	0.06	-0.12	0.38	7.62
95	sL3	74.9	19.1	1.0	0.08	0.05	0.14	7.64
96	sL3	69.6	20.0	1.8	-0.01	0.01	0.24	7.68
98	SL2	58.2	24.3	2.9	-0.05	0.10	0.86	7.68
99	SL2	60.6	26.1	3.6	-0.04	0.06	0.23	7.71
100	SL2	68.5	26.7	2.1	0.04	-0.02	0.23	7.72
102	lS3	70.0	27.6	1.2	0.07	-0.04	0.17	7.73
103	lS3	55.8	29.3	2.5	0.04	-0.03	0.17	7.76

Table A.7 continued

Sample	**Soil**	**Fertilisation mg ha^{-1} P$_2$O$_5$**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
104	lS3	50.6	31.5	1.8	-0.02	-0.01	0.24	7.76
105	lS3	47.0	31.7	0.5	0.01	-0.01	0.17	7.76
106	lS3	45.7	31.8	0.5	-0.01	0.02	0.22	7.77
107	lS3	45.1	30.7	2.1	-0.01	-0.01	0.21	7.78
108	lS3	46.5	31.2	0.3	-0.03	0.02	0.29	7.78
109	lS3	46.9	31.0	0.6	-0.08	0.01	0.28	7.79
110	lS3	47.1	31.3	1.0	0.04	0.01	0.38	7.81
111	lS3	58.4	30.4	1.6	0.03	0.01	0.26	7.81
112	lS3	80.1	29.3	2.0	-0.06	-0.05	0.19	7.82
113	SL2	111	29.2	2.4	0.00	-0.03	0.21	7.83
114	SL2	93.4	28.8	1.7	-0.04	0.07	0.32	7.84
115	SL2	60.3	22.4	2.2	0.02	-0.03	0.19	7.85
116	SL2	61.4	22.1	3.5	0.02	-0.02	0.34	7.85
118	SL2	73.9	20.0	2.4	0.00	-0.07	0.35	7.86
119	sL3	69.8	19.7	2.8	0.01	0.09	0.31	7.91
121	SL2	47.7	18.6	2.4	0.05	-0.02	0.27	7.92
122	sL3	44.8	17.7	1.6	0.00	-0.05	0.08	7.93
123	SL2	42.2	19.0	2.2	-0.11	0.21	0.65	7.94
124	SL2	35.3	19.9	1.5	0.00	0.04	0.20	7.95
125	SL2	29.9	18.7	1.9	-0.05	0.06	0.32	7.95
126	SL2	25.6	17.7	1.8	0.14	0.03	0.33	7.97
127	SL2	13.8	16.5	1.7	-0.02	-0.03	0.15	7.98
128	Sl3	18.3	15.0	2.0	0.05	-0.11	0.35	7.98
129	lS3	26.7	13.1	2.9	-0.02	0.00	0.23	8.00
130	lS3	42.8	9.7	2.8	-0.03	0.09	0.46	8.00
131	SL2	39.6	12.3	3.5	0.07	-0.02	0.33	8.01
132	SL2	35.2	14.3	3.9	0.00	0.02	0.34	8.05
133	SL2	30.5	16.2	2.1	-0.05	0.44	0.37	8.07
134	lS3	37.6	17.9	2.2	0.01	0.03	0.20	8.09
135	SL2	38.2	19.3	1.8	-0.10	0.12	0.35	8.09
136	SL2	37.8	20.5	1.9	-0.01	-0.02	0.09	8.10
137	SL2	39.7	20.9	1.4	0.01	-0.02	0.33	8.11
138	lS3	42.9	19.9	2.6	-0.01	0.10	0.41	8.17
139	lS3	45.8	19.3	1.9	0.05	-0.04	0.29	8.19
140	Sl3	48.9	20.8	2.2	0.02	0.02	0.17	8.20
141	SL2	55.7	21.6	2.1	-0.16	0.10	0.31	8.21
142	SL2	62.3	21.9	2.9	0.06	-0.06	0.09	8.22
143	SL2	61.1	22.6	2.8	-0.04	0.02	0.25	8.22
144	SL2	57.4	23.0	3.7	-0.02	0.00	0.16	8.24
145	SL2	58.1	23.4	2.9	-0.06	0.00	0.37	8.27
146	SL2	65.5	25.2	4.3	-0.01	-0.02	0.34	8.34
147	SL2	75.9	27.8	3.8	-0.10	0.03	0.25	8.36
148	SL2	95.1	29.5	1.1	0.03	0.06	0.38	8.38
149	SL2	94.4	29.8	1.0	-0.06	-0.01	0.20	8.41
151	SL2	52.4	30.2	1.1	0.03	0.02	0.15	8.43
152	SL2	47.3	30.6	1.0	-0.11	0.03	0.42	8.49
153	SL2	48.0	31.0	0.9	0.00	0.01	0.25	8.55
154	SL2	49.7	30.3	2.0	-0.04	0.00	0.17	8.57

Table A.7 continued

Sample	**Soil**	**Fertilisation mg ha^{-1} P$_2$O$_5$**	**Elevation m**	**Slope °**	**PLC**	**PRC**	**LS**	**ω**
155	SL2	50.4	29.5	1.8	0.00	0.02	0.40	8.59
156	lS3	53.1	29.5	1.3	0.00	0.09	0.25	8.68
157	lS3	53.8	29.1	1.7	-0.07	0.02	0.43	8.70
158	lS3	60.6	28.4	2.9	0.04	-0.03	0.32	8.76
159	lS3	63.8	26.6	1.2	-0.03	-0.01	0.31	8.77
160	lS3	63.0	25.8	1.2	-0.04	-0.04	0.14	8.78
161	SL2	56.3	25.5	3.4	-0.05	0.07	0.36	8.81
162	SL2	51.1	26.1	2.6	0.03	0.00	0.30	8.83
163	lS3	49.8	25.7	2.3	-0.07	0.11	0.25	8.84
164	lS3	52.8	24.8	2.1	-0.11	-0.01	0.26	9.07
166	lS3	51.9	23.3	2.0	0.02	-0.01	0.14	9.08
167	lS3	46.4	22.2	2.5	-0.10	-0.02	0.18	9.19
168	lS3	45.5	20.9	1.5	-0.10	-0.02	0.24	9.26
169	lS3	43.4	21.8	1.9	-0.06	0.42	0.34	9.29
170	lS3	40.2	22.4	1.2	-0.08	0.00	0.39	9.31
171	lS3	39.6	21.6	2.1	0.01	0.06	0.21	9.36
172	lS3	42.1	20.6	2.0	-0.03	0.18	0.37	9.36
173	lS3	44.1	19.2	2.3	-0.14	0.00	0.47	9.49
174	lS3	35.4	16.9	2.4	-0.02	-0.03	0.14	9.49
175	SL2	33.5	14.9	3.1	-0.10	-0.10	0.20	9.51
176	SL2	38.3	12.6	2.2	-0.02	0.02	0.13	9.54
178	Sl3	39.3	9.4	2.9	-0.07	-0.03	0.16	9.54
179	lS3	34.9	12.3	5.4	-0.08	0.06	0.44	9.59
180	sL4	27.8	15.4	5.5	-0.11	0.12	0.33	9.78
181	lS3	25.1	16.2	4.2	-0.16	0.04	0.36	10.0
182	SL2	28.7	16.8	2.5	-0.09	-0.01	0.20	10.2
183	lS3	36.7	19.6	3.6	-0.02	0.03	0.33	10.2
184	lS3	39.6	21.3	2.4	-0.10	0.03	0.32	10.3
185	lS3	40.2	23.0	2.0	-0.15	0.04	0.24	10.5
186	lS3	41.2	23.5	1.7	-0.21	0.12	0.40	10.6
187	lS3	44.1	22.6	2.1	-0.12	-0.02	0.32	10.6
188	sL4	45.3	22.3	1.6	-0.16	-0.01	0.27	10.8
189	sL4	46.6	24.1	3.2	-0.03	-0.02	0.46	10.8
190	sL4	50.7	25.7	2.4	-0.42	0.04	0.62	10.8
191	Sl3	51.9	26.3	2.1	0.00	-0.03	0.20	10.8
192	SL2	49.7	26.8	1.5	-0.11	-0.05	0.43	10.9
193	lS3	46.5	27.1	1.5	-0.13	0.02	0.47	11.0
194	lS3	48.3	27.3	0.7	-0.03	0.02	0.47	11.1
195	lS3	48.3	27.3	1.2	0.00	0.14	0.31	11.1
196	sL4	53.0	28.0	2.9	-0.12	0.07	0.24	11.3
197	sL4	55.6	27.9	2.5	-0.05	-0.05	0.29	11.3
198	sL4	55.2	27.1	0.9	0.01	0.06	0.22	11.3
199	sL4	48.7	27.3	0.8	-0.35	-0.03	0.73	11.4
200	Sl3	45.8	27.9	0.6	-0.28	-0.06	0.59	11.5
201	SL2	50.0	28.1	0.6	-0.16	0.11	0.47	11.7
202	SL2	51.5	28.1	1.0	-0.06	0.04	0.38	13.1

PLC = plane curvature; PRC = profile curvature; n.a. = not analysed/not available

Tab. A.8: Calculated and extracted terrain attribute and soil texture classes for sampling points at Warberg (E10º54', N52º 10').

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
BB	**1**	L4	155	2.8	-0.05	0.03	2.28	8.00
BB	**2**	L4	157	4.7	-0.01	0.15	2.70	7.70
BB	**3**	L4	158	5.8	0.00	0.11	3.41	7.47
BB	**4**	L4	159	6.3	0.03	0.08	3.51	7.42
BB	**5**	L4	160	6.0	0.07	-0.03	3.55	7.18
BB	**6**	L4	160	2.5	0.03	-0.04	3.25	7.51
BB	**7**	LT5	161	6.8	0.02	0.16	4.80	7.31
BB	**8**	LT5	163	6.5	0.06	-0.05	3.36	7.09
BB	**9**	L5	164	5.3	0.08	-0.05	2.53	7.31
BB	**10**	L4	163	3.5	0.05	-0.02	2.37	7.67
BB	**11**	LT5	163	7.0	0.01	0.05	6.30	7.93
BB	**12**	LT5	165	5.9	0.08	-0.11	4.77	7.47
BB	**13**	LT5	166	4.8	0.11	-0.07	2.70	7.20
BB	**14**	LT5	166	4.5	0.06	0.00	2.40	7.39
BB	**15**	L4	165	4.2	0.01	0.02	2.27	7.70
BB	**16**	LT5	164	6.6	-0.02	0.21	5.48	7.75
BB	**17**	LT5	166	6.5	-0.01	-0.14	5.97	8.14
BB	**18**	LT5	167	4.9	0.03	-0.14	3.24	8.37
BB	**19**	LT5	168	3.7	0.11	-0.06	2.04	7.88
BB	**20**	LT5	168	3.9	0.05	-0.02	2.13	7.40
BB	**21**	LT5	167	4.3	0.01	0.01	2.26	7.46
BB	**22**	LT5	166	3.2	-0.01	0.01	2.02	7.88
BB	**23**	LT5	165	2.6	-0.19	0.23	6.72	10.5
BB	**24**	LT5	167	5.8	0.10	-0.07	5.38	7.99
BB	**25**	LT5	169	4.2	0.08	-0.11	3.18	8.39
BB	**26**	LT5	170	3.6	-0.03	-0.03	2.77	8.74
BB	**27**	LT5	170	3.2	0.09	-0.02	1.62	7.89
BB	**28**	LT5	170	3.4	0.09	-0.06	1.66	7.40
BB	**29**	LT5	169	4.0	0.03	-0.05	2.00	7.42
BB	**30**	LT5	168	3.9	-0.01	0.03	1.94	7.72
BB	**31**	LT5	167	3.6	-0.43	0.11	6.41	9.85
BB	**32**	LT5	167	5.5	-0.22	0.21	5.75	8.21
BB	**33**	LT5	169	4.2	-0.09	-0.08	5.86	8.67
BB	**34**	LT5	171	2.3	0.11	-0.06	2.51	8.76
BB	**35**	LT5	171	1.5	0.02	-0.05	2.39	8.91
BB	**36**	LT5	172	n.a.	0.06	-0.02	1.81	8.50
BB	**37**	LT5	170	n.a.	-0.04	0.00	4.63	8.23
GB	**1**	L4	150	2.2	-0.07	0.07	2.12	9.82
GB	**2**	L4	152	1.9	-0.10	-0.01	2.80	11.77
GB	**3**	L4	152	2.6	-0.08	0.04	2.65	10.34
GB	**4**	L4	151	2.9	-0.02	0.02	1.82	8.70
GB	**5**	L4	154	2.5	-0.07	0.03	2.06	9.58
GB	**6**	L4	153	2.6	-0.06	0.03	2.65	9.93
GB	**7**	L4	153	2.6	0.02	-0.01	2.02	9.26
GB	**8**	L4	153	2.6	0.05	-0.02	1.53	8.69
GB	**9**	L4	156	3.3	0.04	0.07	1.89	8.44
GB	**10**	L4	156	3.7	0.01	0.08	2.43	8.72
GB	**11**	L4	155	3.8	-0.04	0.06	3.53	9.43
GB	**12**	L4	155	3.6	-0.02	0.04	3.16	9.55

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
GB	**13**	L4	155	2.9	0.03	0.02	2.13	9.26
GB	**14**	L4	154	2.7	0.05	0.01	1.47	8.84
GB	**15**	L4	157	3.2	0.01	0.04	2.28	8.75
GB	**16**	L4	157	3.1	0.06	-0.05	1.89	8.44
GB	**17**	L4	157	3.2	0.03	-0.05	2.44	8.89
GB	**18**	L4	157	3.4	-0.01	-0.02	3.29	9.34
GB	**19**	L4	156	3.5	-0.01	0.01	3.50	9.40
GB	**20**	L4	156	3.3	0.03	0.04	2.73	9.00
GB	**21**	L4	155	3.3	0.04	0.04	2.35	8.76
GB	**22**	L4	159	1.6	-0.07	0.01	3.30	9.82
GB	**23**	L4	159	2.8	0.00	-0.03	1.78	8.74
GB	**24**	L4	159	2.3	0.03	-0.04	1.39	8.80
GB	**25**	L4	159	2.5	0.00	-0.03	1.82	9.31
GB	**26**	L4	159	2.7	0.00	-0.05	2.86	9.67
GB	**27**	L4	158	3.1	0.00	-0.03	3.06	9.31
GB	**28**	L4	158	3.3	0.05	-0.02	2.73	8.80
GB	**29**	L4	157	3.6	0.01	0.00	3.04	8.91
GB	**30**	L4	160	3.1	-0.03	-0.01	2.73	9.43
GB	**31**	L4	160	2.7	0.01	0.01	1.53	8.54
GB	**32**	L4	160	2.4	0.01	0.02	1.38	8.95
GB	**33**	L4	160	2.3	-0.01	0.01	1.66	9.46
GB	**34**	L4	160	2.2	0.00	-0.04	2.06	9.88
GB	**35**	L4	160	2.3	0.03	-0.06	2.21	9.36
GB	**36**	L4	159	2.7	0.07	-0.07	2.24	8.87
GB	**37**	L4	158	3.2	-0.03	-0.03	3.27	9.17
GB	**38**	L4	157	3.5	-0.06	-0.01	3.71	9.24
GB	**39**	L4	162	2.8	0.00	0.00	1.73	8.41
GB	**40**	L4	162	2.9	0.04	0.00	1.59	8.32
GB	**41**	L4	162	2.7	0.00	0.01	1.63	8.90
GB	**42**	L4	162	2.3	-0.01	0.02	1.77	9.42
GB	**43**	L4	161	2.2	-0.01	0.01	1.91	9.93
GB	**44**	L4	161	2.0	0.02	0.00	1.46	9.72
GB	**45**	L4	161	2.1	0.03	-0.03	1.50	9.45
GB	**46**	L4	160	2.6	-0.03	-0.04	2.27	9.41
GB	**47**	L4	160	2.9	0.01	-0.06	2.23	9.05
GB	**48**	L4	164	2.4	-0.02	0.02	1.86	10.05
GB	**49**	L4	164	2.9	0.04	0.01	1.57	8.18
GB	**50**	L4	163	3.0	0.03	0.01	1.66	8.37
GB	**51**	L4	163	3.0	0.01	0.02	1.86	8.79
GB	**52**	L4	163	2.9	-0.01	0.03	2.00	9.38
GB	**53**	L4	162	2.5	0.00	0.02	2.13	9.87
GB	**54**	L4	162	2.4	0.02	0.03	1.67	9.67
GB	**55**	L4	162	2.4	0.00	0.02	1.57	9.57
GB	**56**	L4	161	2.4	-0.01	0.00	1.76	9.31
GB	**57**	L4	161	2.5	0.00	0.00	1.68	9.06
GB	**58**	L4	165	3.2	0.01	0.05	2.29	8.68
GB	**59**	L4	165	3.2	0.07	0.01	1.75	8.20
GB	**60**	L4	165	3.2	0.02	0.02	1.99	8.35
GB	**61**	L4	164	3.3	0.02	0.02	2.32	8.67

Table A.8 continued

Sample	**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
GB 62	L4	164	3.2	-0.01	0.02	2.66	9.25
GB 63	L4	163	2.9	0.00	0.02	2.58	9.60
GB 64	L4	163	2.8	0.02	0.03	2.35	9.32
GB 65	L4	163	2.9	0.00	0.03	2.19	9.13
GB 66	L4	162	2.8	0.00	0.01	1.93	8.95
GB 67	L4	162	2.8	0.02	0.02	1.84	8.78
GB 78	L4	163	3.1	0.04	0.02	2.12	8.72
GB 79	T4	168	4.0	-0.05	0.04	3.70	8.76
GB 80	T4	168	4.0	-0.03	0.00	3.34	8.85
GB 81	T4	168	3.6	0.03	0.00	2.62	8.56
GB 82	L4	168	3.3	0.06	-0.02	1.94	8.28
GB 83	L4	168	3.1	0.03	-0.01	2.03	8.48
GB 84	L4	167	3.2	0.00	-0.01	2.49	8.83
GB 85	L4	167	3.4	-0.04	-0.01	3.01	9.17
GB 86	L4	166	3.4	-0.01	0.01	3.11	9.22
GB 87	L4	166	3.5	0.03	0.00	2.85	8.88
GB 88	L4	166	3.6	0.02	0.01	2.74	8.69
GB 89	L4	165	3.6	0.02	0.02	2.57	8.61
GB 90	L4	165	3.5	0.03	0.02	2.43	8.67
GB 91	T4	170	3.5	-0.02	-0.01	3.08	8.63
GB 92	L4	171	3.6	0.03	0.00	2.46	8.49
GB 93	L4	170	3.2	0.04	0.01	1.88	8.45
GB 94	L4	170	2.9	0.02	-0.01	1.90	8.67
GB 95	L4	169	3.0	0.00	-0.02	2.23	8.87
GB 96	L4	169	3.1	-0.02	-0.03	2.54	9.10
GB 97	L4	168	3.0	-0.01	-0.03	2.54	9.19
GB 98	L4	168	3.1	0.03	-0.03	2.44	8.87
GB 99	L4	168	3.3	0.01	-0.01	2.48	8.82
GB 100	L4	167	3.4	0.03	0.00	2.47	8.58
GB 101	L4	167	3.5	0.01	-0.01	2.65	8.80
GB 102	L4	165	3.4	0.00	0.02	2.93	9.12
GB 103	L4	172	2.0	0.04	-0.01	2.32	8.51
GB 104	L4	172	3.1	0.05	0.01	1.91	8.53
GB 105	L4	171	3.0	-0.01	0.03	1.93	8.73
GB 106	L4	171	2.8	0.01	-0.01	1.89	8.93
GB 107	L4	170	2.7	-0.01	-0.01	2.06	9.21
GB 108	L4	170	2.5	-0.02	-0.03	1.95	9.26
GB 109	L4	170	2.4	0.03	-0.04	1.87	9.11
GB 110	L4	169	2.6	0.01	-0.03	2.09	9.03
GB 111	L4	169	2.9	0.05	-0.02	2.17	8.67
GB 112	L4	168	3.0	0.00	-0.02	2.65	9.12
GB 113	L4	167	3.2	0.05	0.00	2.86	9.18
GB 114	L4	173	1.9	0.01	0.03	2.14	8.41
GB 115	L4	173	3.3	0.00	0.03	2.20	8.49
GB 116	L4	172	3.1	0.01	0.03	2.18	8.91
GB 117	L4	171	2.9	-0.02	0.02	2.01	8.98
GB 118	L4	171	2.6	0.00	0.00	1.71	9.17
GB 119	L4	171	2.3	0.01	-0.01	1.62	9.46
GB 120	L4	171	2.2	0.02	-0.02	1.66	9.20

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
GB	**121**	L4	170	2.5	0.02	-0.03	2.08	9.05
GB	**122**	L4	169	2.8	-0.01	-0.01	2.38	9.44
GB	**123**	L4	168	3.0	0.00	0.00	2.78	9.22
GB	**124**	L4	175	2.8	0.00	0.03	2.41	8.49
GB	**125**	L4	174	3.6	-0.01	0.02	2.45	8.64
GB	**126**	L4	173	3.1	0.01	0.02	2.13	8.67
GB	**127**	L4	172	2.7	-0.01	0.03	1.87	8.93
GB	**128**	L4	172	2.3	-0.01	0.02	1.65	9.52
GB	**129**	L4	172	2.1	0.04	0.00	1.53	9.47
GB	**130**	L4	171	2.4	0.00	-0.02	2.12	9.49
GB	**131**	L4	170	2.7	0.02	0.00	2.12	9.34
GB	**132**	L4	169	2.8	-0.04	-0.02	2.36	9.22
GB	**133**	L4	175	2.0	0.01	0.00	2.42	8.48
GB	**134**	L4	174	3.4	0.03	0.00	2.18	8.55
GB	**135**	L4	174	3.1	0.00	0.02	2.14	8.94
GB	**136**	L4	173	2.8	0.01	0.03	1.83	9.44
GB	**137**	L4	173	2.3	0.02	0.01	1.71	9.64
GB	**138**	L4	172	2.4	0.01	-0.01	1.97	9.47
GB	**139**	L4	171	2.6	0.00	0.00	1.99	9.16
GB	**140**	L4	170	2.6	-0.01	-0.02	1.89	9.14
GB	**141**	L4	176	1.8	0.00	0.01	2.25	8.54
GB	**142**	L4	175	3.2	0.00	0.01	2.42	8.90
GB	**143**	L4	175	2.9	0.02	0.01	2.38	9.44
GB	**144**	L4	174	2.5	-0.02	0.02	2.24	9.69
GB	**145**	L4	173	2.5	0.01	0.00	1.79	9.06
GB	**146**	L4	173	2.7	-0.01	0.00	1.74	8.75
GB	**147**	L4	172	2.6	0.03	0.00	1.52	8.60
GB	**148**	L4	176	1.5	0.01	0.01	2.38	9.07
GB	**149**	L4	176	2.9	-0.02	0.00	2.53	9.57
GB	**150**	L4	175	2.7	-0.03	0.02	2.20	9.40
GB	**151**	L4	174	2.7	0.01	0.00	1.71	8.73
GB	**152**	L4	174	2.8	0.01	0.00	1.67	8.45
GB	**153**	L4	173	2.8	0.02	0.02	1.49	8.37
GB	**154**	L4	172	2.5	0.02	0.00	1.31	8.38
GB	**155**	L4	177	2.3	-0.02	0.02	2.39	9.30
GB	**156**	L4	176	2.8	0.00	0.01	1.82	8.77
GB	**157**	L4	175	2.7	0.03	-0.02	1.50	8.48
GB	**158**	L4	175	2.8	0.03	0.00	1.49	8.21
GB	**159**	L4	174	2.9	0.02	0.01	1.51	8.17
GB	**160**	L4	173	2.7	0.04	0.00	1.32	8.20
GB	**161**	LT4	178	1.5	0.01	-0.01	1.50	8.68
GB	**162**	LT4	177	2.3	0.03	-0.02	1.28	8.35
GB	**163**	LT4	176	2.5	0.02	-0.02	1.30	8.15
GB	**164**	LT4	175	2.9	0.02	0.00	1.45	8.07
GB	**165**	LT4	174	2.9	0.04	0.01	1.36	7.90
GB	**166**	LT4	178	1.2	0.04	0.00	0.95	8.33
GB	**167**	LT4	177	2.1	0.03	-0.04	1.00	8.28
GB	**168**	LT4	176	2.4	0.05	-0.03	1.23	8.05
GB	**201**	L4	154	3.1	-0.05	0.05	2.98	9.61

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
GB	**202**	L5	161	2.5	-0.03	-0.04	2.37	9.84
GB	**203**	L4	168	n.a.	0.02	-0.01	2.45	8.71
M1	**1**	L4	145	3.4	-0.02	0.09	1.77	7.93
M1	**2**	L4	144	3.3	0.02	0.08	1.69	7.96
M1	**3**	L4	143	3.2	0.00	0.09	1.39	8.38
M1	**4**	L4	143	2.1	-0.01	0.04	1.50	9.95
M1	**5**	L4	142	1.4	-0.02	0.01	2.72	11.4
M1	**6**	L4	147	n.a.	0.05	-0.04	1.30	8.23
M1	**7**	L4	145	2.7	0.08	-0.03	1.75	8.49
M1	**8**	L4	144	3.0	0.02	0.04	2.67	9.60
M1	**9**	L4	143	2.2	-0.02	0.05	3.62	11.4
M1	**10**	L4	143	1.9	0.00	-0.03	2.34	11.1
M1	**11**	L4	148	2.1	0.05	-0.01	1.28	9.09
M1	**12**	L4	146	2.4	0.01	-0.03	1.83	9.43
M1	**13**	L4	145	2.6	-0.06	0.01	4.13	11.3
M1	**14**	L4	144	2.4	-0.07	0.01	3.90	11.4
M1	**15**	L4	144	2.4	-0.02	0.03	1.87	9.94
M1	**16**	L4	147	2.1	-0.09	-0.02	2.96	11.0
M1	**17**	L4	146	2.3	-0.10	0.00	3.77	11.3
M1	**18**	L4	145	2.7	0.00	0.02	2.30	9.64
M1	**19**	L4	145	2.6	-0.02	0.01	2.00	9.69
M1	**20**	L4	147	2.3	-0.08	0.01	2.52	10.2
M1	**21**	L4	147	2.5	-0.01	-0.01	2.03	9.35
M1	**22**	L4	147	2.7	0.04	0.00	1.90	9.04
M1	**23**	L4	146	2.6	-0.03	0.03	2.07	9.71
M1	**24**	L4	149	2.7	-0.01	0.01	2.46	9.80
M1	**25**	L4	148	2.7	0.01	0.01	1.95	9.20
M1	**26**	L4	148	2.8	0.01	0.00	2.07	9.13
M1	**27**	L4	147	2.9	-0.02	0.03	2.32	9.51
M1	**28**	L4	147	1.8	0.00	0.02	1.98	9.85
M1	**29**	L4	150	3.1	0.01	0.02	2.60	9.24
M1	**30**	L4	150	2.9	0.02	0.03	2.25	9.13
M1	**31**	L4	149	2.9	0.01	0.00	2.29	9.17
M1	**32**	L4	148	3.0	0.00	0.01	2.42	9.29
M1	**33**	L4	148	2.8	-0.01	0.02	2.31	9.77
M1	**34**	L4	152	3.2	0.03	0.01	2.54	9.04
M1	**35**	L4	151	3.1	0.02	0.00	2.42	9.13
M1	**36**	L4	151	3.0	0.05	0.00	2.41	9.11
M1	**37**	L4	150	3.0	0.00	0.02	2.48	9.56
M1	**38**	L4	149	2.7	-0.07	0.03	2.19	9.60
M1	**39**	L4	153	3.3	0.02	0.02	2.65	9.03
M1	**40**	L4	153	3.2	0.02	0.00	2.53	9.14
M1	**41**	L4	152	3.0	0.05	-0.01	2.60	9.29
M1	**42**	L4	151	3.2	-0.08	0.04	2.79	9.40
M1	**43**	L5	150	3.3	-0.04	0.05	1.96	8.60
M1	**44**	L4	154	3.1	0.00	0.00	2.80	9.51
M1	**45**	L4	154	3.1	-0.08	0.02	2.86	9.38
M1	**46**	L5	153	3.5	0.02	-0.02	2.05	8.02
M1	**47**	L5	152	3.5	0.01	0.01	1.82	7.82

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
M1	**48**	L5	155	3.1	-0.08	0.01	2.79	9.42
M1	**49**	L5	155	3.5	-0.02	0.01	2.33	8.50
M1	**50**	L5	154	3.5	0.04	0.00	1.76	7.78
M1	**51**	L5	154	3.4	0.02	0.01	1.63	7.69
M1	**52**	L5	153	2.2	0.03	0.02	1.41	7.76
M1	**53**	L5	157	3.4	-0.05	0.01	2.18	8.40
M1	**54**	L5	156	3.3	0.03	-0.02	1.74	8.00
M1	**55**	L5	156	3.3	0.04	-0.01	1.54	7.57
M1	**56**	L5	155	3.3	0.04	0.00	1.40	7.41
M1	**57**	L5	154	2.1	0.03	0.03	1.13	7.33
M1	**58**	L5	159	3.4	0.00	0.00	1.88	8.20
M1	**59**	L5	158	2.9	0.04	0.00	1.42	7.98
M1	**60**	L5	157	2.8	0.07	-0.03	1.13	7.53
M1	**61**	L5	157	2.3	0.06	-0.01	1.13	7.25
M1	**62**	L4	160	3.2	0.03	0.00	1.67	8.03
M1	**63**	L4	159	2.9	0.04	0.02	1.31	7.82
M1	**64**	L5	158	2.9	0.11	0.00	0.96	7.36
M1	**65**	L4	162	3.1	0.05	0.01	1.35	7.69
M1	**66**	L4	161	3.0	0.09	-0.02	1.16	7.34
M2	**2**	L4	150	2.5	0.01	0.01	1.43	8.62
M2	**3**	L4	151	2.4	0.05	0.00	1.30	8.57
M2	**4**	L4	152	2.4	0.03	0.03	1.37	8.89
M2	**5**	L4	153	2.4	0.02	0.02	1.76	9.49
M2	**6**	L4	153	3.0	-0.02	0.04	2.56	9.74
M2	**7**	L5	155	3.8	-0.02	0.04	3.49	9.12
M2	**8**	L5	156	4.0	0.03	-0.02	3.24	8.63
M2	**9**	L5	158	3.5	0.02	-0.03	2.95	8.72
M2	**10**	L5	160	2.9	-0.02	-0.05	2.90	9.46
M2	**11**	L5	161	2.7	-0.03	-0.04	2.54	9.74
M2	**12**	L5	162	2.6	0.01	-0.02	2.40	9.71
M2	**13**	L5	163	2.6	-0.01	0.01	2.27	9.73
M2	**14**	L4	164	2.6	0.02	-0.02	2.19	9.99
M2	**15**	L4	166	2.3	-0.09	0.02	2.20	10.1
M2	**16**	L4	166	2.7	-0.01	0.01	1.52	9.34
M2	**17**	L4	167	2.8	-0.01	0.05	1.63	8.83
M2	**18**	L4	168	2.8	0.01	0.02	1.73	8.44
M2	**19**	L4	170	2.6	0.04	-0.01	1.36	8.31
M2	**20**	L4	170	2.7	0.02	0.00	1.30	8.21
M2	**21**	L5	171	2.8	0.06	-0.01	1.27	8.02
M2	**22**	L4	169	2.7	0.04	-0.03	1.48	8.04
M2	**23**	L4	169	2.6	0.05	-0.01	1.33	8.20
M2	**24**	L4	168	2.5	0.05	0.04	1.18	8.29
M2	**25**	L4	167	2.3	0.00	0.05	1.20	8.61
M2	**26**	L4	166	2.0	0.07	-0.04	0.96	8.79
M2	**27**	L4	165	2.3	0.02	-0.03	1.81	9.26
M2	**28**	L4	164	2.4	0.01	-0.04	2.46	9.67
M2	**29**	L5	162	2.6	0.07	-0.04	2.28	9.67
M2	**30**	L5	161	2.7	0.06	-0.03	2.59	9.23
M2	**31**	L5	160	3.1	0.02	-0.02	2.99	9.50

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
M2	**32**	L5	158	3.3	0.00	-0.03	3.45	9.55
M2	**33**	L5	157	3.6	-0.01	-0.01	3.73	9.29
M2	**34**	L5	156	4.0	-0.03	0.01	3.76	9.09
M2	**34a**	L5	153	3.9	-0.04	0.06	3.42	9.11
M2	**35**	L4	153	3.1	-0.04	0.05	2.40	9.81
M2	**36**	L4	152	2.2	0.01	0.01	1.77	9.97
M2	**37**	L4	151	2.0	0.02	0.02	1.09	9.28
M2	**38**	L4	151	1.9	0.05	0.00	0.84	8.95
M2	**39**	L4	150	2.4	0.00	-0.03	1.22	8.42
M2	**40**	L4	149	2.5	0.05	-0.07	1.19	8.25
M2	**42**	L4	150	1.7	0.05	-0.02	0.83	8.85
M2	**43**	L4	150	1.9	0.01	0.01	1.39	9.68
M2	**44**	L4	151	2.0	0.00	-0.01	1.92	10.1
M2	**45**	L4	151	2.5	-0.03	0.00	2.27	9.87
M2	**46**	L4	153	3.6	-0.01	0.04	3.28	9.54
M2	**47**	L4	155	3.7	-0.01	0.01	3.89	9.47
M2	**48**	L4	156	3.7	0.01	0.00	3.71	9.45
M2	**49**	L4	158	3.6	0.02	-0.01	3.53	9.34
M2	**50**	L5	159	3.4	0.01	-0.02	2.98	9.16
M2	**51**	L5	160	3.2	0.02	-0.01	2.87	9.22
M2	**52**	L5	161	3.2	-0.07	0.02	3.10	9.56
M2	**53**	L4	163	3.2	-0.03	0.00	2.68	8.96
M2	**54**	L4	164	2.5	0.03	-0.04	1.58	8.23
M2	**55**	L4	165	2.2	0.02	-0.04	1.22	8.46
M2	**56**	L4	166	2.1	0.04	-0.02	0.90	8.17
M2	**57**	L4	167	2.6	0.08	-0.02	1.02	8.10
M2	**58**	L5	167	3.2	0.02	-0.07	1.88	7.90
M2	**59**	L5	165	3.7	0.01	-0.13	2.01	7.78
M2	**60**	L4	166	2.2	0.11	-0.06	0.99	7.64
M2	**61**	L4	165	2.3	0.05	-0.02	1.18	7.92
M2	**62**	L4	164	2.7	0.03	-0.03	1.62	8.27
M2	**63**	L4	162	3.3	0.02	0.00	1.91	8.23
M2	**64**	L5	161	3.3	-0.01	0.00	2.43	8.83
M2	**65**	L5	159	3.1	0.01	-0.01	3.00	9.46
M2	**66**	L5	158	3.2	0.02	0.00	3.04	9.29
M2	**67**	L4	157	3.5	-0.03	0.01	3.07	9.33
M2	**68**	L4	156	3.4	-0.03	0.00	3.45	9.48
M2	**69**	L4	153	3.6	-0.02	0.01	3.67	9.59
M2	**70**	L4	152	3.5	-0.03	0.04	3.59	9.70
M2	**91**	L4	151	2.7	-0.05	0.04	2.98	10.1
M2	**92**	L4	150	2.2	-0.02	0.00	2.31	10.3
M2	**93**	L4	150	2.0	0.01	0.00	1.66	10.1
M2	**94**	L4	150	1.7	0.05	0.00	0.84	9.10
M2	**95**	L4	149	1.9	0.05	-0.06	1.08	8.37
M2	**96**	L4	148	2.2	0.08	-0.07	0.99	8.35
M2	**97**	L4	149	1.8	0.03	-0.02	1.21	9.28
M2	**98**	L4	149	2.0	-0.01	-0.01	1.73	10.1
M2	**99**	L4	149	2.2	-0.06	0.01	2.61	11.0
M2	**100**	L4	150	2.8	-0.05	0.03	3.02	10.3

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
M2	**101**	L4	152	3.2	-0.02	0.02	3.18	9.64
M2	**102**	L4	153	3.4	0.00	0.00	3.19	9.45
M2	**103**	L4	154	3.3	0.04	0.00	2.73	9.09
M2	**104**	L4	156	3.1	0.06	-0.01	2.55	9.15
M2	**105**	L5	157	3.2	0.01	0.01	2.77	9.42
M2	**106**	L5	158	3.5	-0.06	0.02	2.97	9.10
M2	**107**	L5	159	3.4	-0.01	-0.01	2.07	8.22
M2	**108**	L4	161	3.3	0.02	-0.01	1.86	8.13
M2	**109**	L4	163	3.1	0.04	0.02	1.40	7.67
M2	**110**	L4	163	3.1	0.04	0.02	1.40	7.67
M2	**111**	L4	163	3.7	0.07	-0.13	2.12	7.07
M2	**112**	L4	163	3.1	0.13	-0.01	1.13	7.23
M2	**113**	L4	162	3.1	0.06	0.01	1.25	7.52
M2	**114**	L4	160	3.2	0.00	0.00	1.72	8.07
M2	**115**	L5	159	3.4	-0.01	0.00	2.11	8.27
M2	**116**	L5	158	3.5	-0.04	0.01	2.69	8.80
M2	**117**	L5	157	3.1	-0.06	0.02	2.85	9.47
M2	**118**	L4	155	3.1	0.05	-0.02	2.58	9.25
M2	**119**	L4	154	3.3	0.03	0.01	2.68	8.99
M2	**120**	L4	153	3.3	0.03	0.01	2.62	9.07
M2	**121**	L4	152	3.2	0.03	0.01	2.86	9.36
M2	**122**	L4	150	2.6	0.01	0.02	2.65	9.84
M2	**123**	L4	148	1.9	-0.09	0.01	2.85	11.2
M2	**124**	L4	148	1.9	0.00	-0.01	1.99	10.4
M2	**125**	L4	148	1.9	0.05	-0.01	1.17	8.95
M2	**126**	L4	147	1.6	0.07	-0.05	1.24	8.11
M3	**1**	L5	155	1.7	0.12	0.00	0.91	7.11
M3	**2**	L5	157	3.2	0.11	0.00	1.01	7.16
M3	**3**	L5	155	3.5	0.09	-0.06	1.13	7.02
M3	**4**	L5	159	n.a.	0.09	-0.06	1.63	6.85
M3	**5**	L5	157	4.0	0.02	0.02	1.77	7.12
M3	**7**	L4	162	3.9	0.11	-0.02	1.25	7.04
M3	**8**	L5	159	5.3	0.03	-0.01	2.40	6.75
M3	**9**	L5	157	3.5	-0.06	0.14	1.95	7.41
M3	**10**	L5	155	2.3	-0.11	0.01	2.51	9.81
M3	**12**	L5	162	5.2	0.05	-0.14	2.01	6.85
M3	**13**	L5	158	5.1	-0.03	0.15	2.28	7.53
M3	**14**	L5	156	2.6	-0.11	0.08	4.95	11.6
M3	**16**	L5	163	4.9	0.02	-0.09	2.74	7.22
M3	**17**	L5	161	5.3	0.02	0.06	3.19	7.33
M3	**18**	L5	158	3.6	-0.15	0.06	4.51	11.1
M3	**20**	L5	165	4.2	-0.01	-0.12	2.01	7.78
M3	**21**	L5	163	5.5	-0.02	0.00	3.69	7.61
M3	**22**	L5	160	3.6	-0.05	0.18	2.81	8.07
M3	**23**	L5	159	2.2	-0.21	0.00	6.32	12.6
M3	**25**	L5	165	5.1	0.00	-0.06	3.51	7.35
M3	**26**	L5	162	5.8	-0.04	0.11	3.30	7.64
M3	**27**	L5	161	2.6	-0.13	0.16	6.11	12.1
M3	**29**	L5	168	3.3	0.06	-0.10	1.88	7.52

Table A.8 continued

Sample		**Texture**	**Elevation (m)**	**Slope**	**PLC**	**PRC**	**LS**	**ω**
M3	**30**	L5	165	5.8	0.01	-0.01	3.18	7.14
M3	**31**	L5	163	5.0	-0.15	0.22	5.54	9.79
M3	**33**	L5	170	3.1	0.07	-0.05	1.63	7.65
M3	**34**	L5	169	4.6	0.06	-0.14	2.24	7.38
M3	**35**	L5	165	5.4	-0.07	0.13	3.41	7.51
M3	**37**	LT4	173	3.2	0.06	-0.01	1.43	7.61
M3	**38**	LT4	170	3.7	0.03	-0.05	1.99	7.37
M3	**39**	L5	169	4.3	-0.01	-0.04	2.51	7.55
M3	**41**	LT4	173	4.0	0.09	-0.06	1.67	7.33
M3	**42**	LT4	170	3.9	0.01	-0.01	2.13	7.57
M3	**44**	LT4	176	n.a.	0.09	-0.08	1.77	7.56
M3	**45**	LT4	176	n.a	0.10	-0.07	1.10	8.01
M3	**46**	LT4	173	3.6	-0.01	0.05	2.18	7.65
M3	**47**	LT4	169	3.5	-0.17	-0.06	7.50	11.5

PLC = plane curvature; PRC = profile curvature; n.a. = not analysed/not available

Tab. A.9: Calculated and extracted terrain attributes, soil types, geological formations and land use for sampling points at Ceveiro (W47º47’, S22º 40’).

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
1001	214529	7492231	Piramboia	Arenic Paleudult	Cane	518	6.17	0.02	-0.17	0.64	6.22
1002	214793	7492199	Piramboia	Psammentic Paleudult	Cane	500	8.79	0.10	-0.36	1.29	6.69
1003	215210	7492338	Piramboia	Arenic Paleudult	Cane	503	5.28	0.01	-0.01	0.88	7.08
1004	215458	7491897	Corumbatia	Arenic Paleudult	Cane	487	12.9	-0.71	0.27	2.28	7.10
1005	215472	7491541	Corumbatia	Typic Udorthent	Cane	475	8.05	0.09	0.20	1.15	5.99
1006	215672	7491629	Corumbatia	Alluvium	Pasture	465	1.08	0.05	-0.02	0.55	8.44
1007	216046	7491183	Corumbatia	Typic Paleudult	Pasture	494	8.14	-0.37	0.25	1.30	7.10
1008	216382	7491095	Corumbatia	Psammentic Paleudult	Cane	503	5.40	-0.09	0.05	0.63	8.64
1009	216116	7491522	Corumbatia	Typic Paleudult	Cane	482	4.12	0.06	0.08	0.90	7.24
1010	215914	7491713	Corumbatia	Typic Udorthent	Cane	464	1.50	0.01	0.01	1.48	9.38
1011	215689	7492012	Corumbatia	Arenic Paleudult	Cane	477	7.29	-0.03	0.12	2.01	6.98
1012	215371	7492516	Piramboia	Arenic Paleudult	Cane	514	0.16	0.00	0.03	0.17	9.92
1015	217094	7493187	Piramboia	Arenic Paleudult	Cane	510	1.78	-0.02	-0.11	0.24	7.92
1016	216380	7493357	Piramboia	Arenic Paleudult	Cane	540	4.76	0.01	-0.17	0.57	6.64
1017	216484	7493156	Piramboia	Arenic Paleudalf	Cane	517	6.44	0.05	-0.03	2.52	6.84
1018	216706	7493039	Corumbatia	Typic Udorthent	Cane	488	9.38	0.42	0.02	2.33	6.21
1019	216933	7493773	Piramboia	Arenic Paleudult	Cane	520	0.29	0.00	0.07	0.19	9.94
1020	217094	7493187	Piramboia	Arenic Paleudult	Cane	510	1.78	-0.02	-0.11	0.24	7.92
1021	217365	7492795	Corumbatia	Typic Eutrochrept	Cane	481	5.52	-0.10	-0.04	2.06	7.57
1022	217481	7492610	Corumbatia	Typic Udorthent	Forest	474	1.00	-0.05	-0.04	0.59	9.97
1023	217735	7492241	Corumbatia	Typic Udorthent	Cane	498	4.80	0.10	0.01	0.77	6.78
1024	217602	7491930	Corumbatia	Typic Paleudalf	Pasture	512	2.98	0.08	-0.01	0.37	6.88
1025	218089	7491846	Piramboia	Typic Paleudalf	Cane	524	2.19	0.10	-0.18	0.21	6.76
1026	218328	7491907	Piramboia	Typic Udorthent	Forest	506	3.87	-0.01	0.34	2.05	9.48

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
1027	218849	7492074	Corumbatia	Typic Udorthent	Pasture	528	3.98	0.03	0.01	0.39	7.45
1028	218551	7492728	Corumbatia	Typic Udorthent	Cane	511	1.44	0.04	0.00	0.25	7.63
1029	218697	7493168	Corumbatia	Arenic Endoaquult	Pasture	484	1.34	0.00	0.00	1.07	9.17
1030	219316	7492002	Corumbatia	Typic Paleudalf	Cane	531	3.46	0.02	-0.03	0.42	7.56
1031	219427	7491929	Corumbatia	Typic Udorthent	Cane	532	4.71	0.04	-0.16	0.53	7.65
1032	220057	7492050	Corumbatia	Typic Udorthent	Cane	551	2.21	0.03	-0.03	0.35	7.40
1033	219807	7492274	Corumbatia	Typic Udorthent	Cane	536	3.23	0.02	-0.04	0.64	7.70
1034	220098	7492207	Corumbatia	Typic Udorthent	Cane	542	0.00	0.00	0.00	0.66	11.25
1036	219281	7493010	Corumbatia	Typic Udorthent	Cane	531	1.62	0.02	-0.02	0.26	7.81
1037	219822	7493244	Corumbatia	Typic Paleudalf	Cane	534	7.31	0.06	0.18	1.23	6.28
1038	219120	7493520	Corumbatia	Typic Paleudalf	Cane	495	2.05	0.05	0.00	0.48	7.64
1039	218783	7493313	Corumbatia	Arenic Endoaquult	Pasture	485	0.94	-0.04	0.00	2.29	11.59
1040	219100	7494109	Corumbatia	Typic Udorthent	Cane	516	4.53	-0.02	0.11	1.08	7.58
1041	219110	7494460	Corumbatia	Typic Udorthent	Cane	520	6.84	0.03	-0.20	1.31	6.85
1042	219689	7494603	Corumbatia	Typic Paleudalf	Cane	550	4.03	0.31	-0.20	0.49	6.58
1043	219270	7492736	Corumbatia	Typic Eutrochrept	Cane	527	3.09	0.18	0.00	0.50	6.91
1044	220547	7492892	Corumbatia	Typic Udorthent	Cane	547	4.86	-0.36	0.06	1.01	8.07
1045	220461	7493237	Corumbatia	Typic Udorthent	Cane	527	4.87	0.23	-0.07	0.87	6.45
1046	220865	7493082	Corumbatia	Typic Udorthent	Cane	556	3.50	0.10	-0.01	0.48	6.89
1048	220757	7494425	Serra Geral	Rhodic Paleudalf	Cane	572	0.50	0.00	-0.09	0.09	7.73
1049	220768	7494129	Corumbatia	Arenic Paleudult	Cane	560	7.66	0.17	-0.33	1.10	6.04
1050	219780	7495131	Serra Geral	Typic Paleudalf	Cane	566	3.00	0.11	-0.04	0.34	6.85
1051	219331	7495238	Piramboia	Arenic Paleudalf	Cane	564	2.58	0.07	-0.22	0.26	7.12
1052	218761	7495042	Corumbatia	Arenic Paleudult	Cane	555	8.35	0.02	-0.35	1.05	6.49
1053	218415	7494744	Piramboia	Arenic Paleudult	Cane	554	0.58	0.00	-0.10	0.10	7.58
1054	218635	7495836	Piramboia	n.a.	Forest	n.a.	n.a.	n.a.	n.a.	0.37	6.57

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope °**	**PLC**	**PRC**	**LS**	**ω**
1055	218459	7495722	Piramboia	Urban	n.a.	581	2.75	0.09	-0.04	n.a.	n.a.
1056	218348	7495094	Serra Geral	Mollic Paleudalf	Cane	542	11.2	0.01	-0.33	1.57	7.15
1057	218014	7494750	Serra Geral	Arenic Paleudult	Cane	521	5.19	-0.18	0.02	3.30	9.81
1058	217880	7495506	Piramboia	Typic Eutrochrept	Cane	550	4.84	0.42	-0.12	0.67	5.94
1059	215323	7491114	Corumbatia	Typic Udorthent	Pasture	462	5.34	0.14	0.12	1.09	6.38
1060	214987	7491474	Corumbatia	Typic Udorthent	Cane	482	6.60	0.05	-0.12	0.66	6.06
1061	214872	7491368	Corumbatia	Typic Udorthent	Cane	490	3.74	0.29	-0.26	0.45	6.66
1062	216817	7491408	Piramboia	Psammentic Paleudult	Cane	505	3.12	0.11	0.01	0.57	7.11
1063	216464	7491782	Corumbatia	Typic Paleudult	Cane	486	3.78	0.06	-0.01	0.55	6.82
1064	216192	7491886	Corumbatia	Typic Udorthent	Forest	465	1.57	0.00	0.00	1.32	8.91
1065	216852	7491937	Corumbatia	Typic Paleudult	Cane	486	5.74	0.01	-0.04	1.05	6.85
1066	221120	7493402	Corumbatia	Typic Udorthent	Pasture	547	11.6	-0.35	-0.17	1.68	7.41
1067	220118	7494278	Corumbatia	Arenic Paleudult	Cane	544	5.94	0.00	-0.09	1.01	6.72
1068	219754	7494101	Corumbatia	Typic Udorthent	Cane	524	1.23	0.00	0.16	0.39	7.78
1069	220479	7494141	Corumbatia	Typic Udorthent	Cane	549	6.29	0.01	-0.11	1.11	6.65
1070	219317	7494016	Corumbatia	Typic Paleudalf	Cane	505	3.16	0.03	-0.02	0.55	7.48
1071	218696	7493942	Corumbatia	Typic Udorthent	Cane	527	6.09	0.06	0.03	0.99	6.48
1072	217572	7495321	Piramboia	Arenic Paleudult	Cane	549	5.40	0.04	-0.17	0.46	6.22
1073	217582	7495090	Piramboia	Arenic Paleudult	Cane	535	3.85	0.21	0.02	0.59	6.44
1074	217658	7494741	Serra Geral	Typic Udorthent	Cane	509	5.67	0.74	-0.35	0.70	5.76
1075	217383	7494965	Piramboia	Arenic Paleudult	Cane	534	5.56	0.12	0.05	1.00	6.47
1076	217624	7494651	Serra Geral	Mollic Paleudalf	Forest	502	3.05	-0.13	0.29	2.87	10.35
1077	217505	7494678	Serra Geral	Mollic Paleudalf	Cane	514	5.20	0.19	-0.17	0.72	6.31
1078	217405	7494373	Piramboia	Arenic Paleudult	Cane	501	6.20	-0.03	-0.13	1.68	7.18
1079	216972	7494536	Piramboia	Arenic Paleudult	Cane	543	0.41	0.06	-0.21	0.15	6.78
1080	217471	7494182	Corumbatia	Typic Udorthent	Cane	497	6.89	0.12	0.14	1.47	6.72

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
1081	217712	7493870	Corumbatia	Typic Paleudult	Cane	509	6.14	0.05	-0.22	0.72	6.60
1082	215891	7490851	Corumbatia	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1083	216547	7491227	Corumbatia	Typic Paleudult	Cane	502	4.06	-0.15	0.37	1.22	7.84
1084	216357	7491526	Corumbatia	Rhodic Paleudalf	Cane	476	4.24	0.03	-0.01	1.34	7.43
1085	216286	7491552	Corumbatia	Typic Udorthent	Cane	472	3.03	0.00	0.29	0.95	7.39
1086	215635	7491289	Corumbatia	Alluvium	Pasture	465	0.74	0.00	-0.01	0.60	9.59
1087	215366	7491701	Corumbatia	Arenic Paleudult	Cane	487	8.20	0.11	-0.04	1.21	5.75
1088	215088	7491952	Corumbatia	Typic Udorthent	Cane	482	10.5	0.29	0.01	2.22	6.08
1089	214647	7491861	Piramboia	Arenic Paleudult	Cane	508	4.73	-0.02	-0.03	0.46	6.36
1090	214849	7491874	Piramboia	Arenic Paleudalf	Cane	492	6.61	0.22	-0.14	1.59	6.36
1091	217534	7492542	Corumbatia	Typic Paleudalf	Cane	478	3.74	0.05	-0.01	0.84	7.45
1092	217365	7493456	Corumbatia	Arenic Paleudult	Cane	498	2.75	0.07	0.00	0.94	7.86
1093	216768	7494425	Piramboia	Arenic Paleudult	Cane	533	4.73	0.16	-0.74	0.42	5.98
1094	217698	7493410	Corumbatia	Typic Udorthent	Cane	485	5.16	0.03	0.18	1.65	7.36
1095	218084	7493268	Corumbatia	Typic Udorthent	Cane	482	5.39	0.00	0.43	1.69	7.48
1096	218334	7493177	Corumbatia	Typic Kandiaqualf	Forest	481	0.33	0.01	0.00	0.34	9.60
1097	218611	7492420	Corumbatia	Typic Udorthent	Cane	518	3.77	0.02	-0.01	0.58	6.96
1098	218019	7492733	Corumbatia	Typic Udorthent	Cane	500	4.34	0.19	-0.13	0.66	6.89
1099	218076	7493018	Corumbatia	Typic Udorthent	Cane	482	1.81	0.05	0.22	1.14	7.92
1113	219506	7494423	Corumbatia	Typic Udorthent	Cane	524	5.95	0.35	-0.12	1.31	6.23
1114	219943	7494827	Corumbatia	Typic Paleudalf	Cane	566	1.84	0.04	0.14	0.31	7.12
1115	217821	7494164	Corumbatia	Typic Paleudalf	Cane	517	5.19	-0.06	0.11	1.06	7.70
1116	218133	7494057	Corumbatia	Typic Paleudalf	Cane	522	4.93	0.05	-0.03	0.87	6.61
1117	218148	7493743	Corumbatia	Typic Udorthent	Pasture	495	5.89	0.09	-0.13	1.08	6.64
1118	218267	7493647	Corumbatia	Typic Udorthent	Cane	492	4.22	-0.15	0.63	1.05	7.52
1119	218136	7493601	Corumbatia	Typic Udorthent	Pasture	488	5.04	-0.08	0.11	1.94	8.25

Table A.9 continued

Sample	Easting m	Northing m	Geo	Soil	Use	Elevation m	Slope °	PLC	PRC	LS	ω
1120	220264	7492772	Piramboia	Psammentic Paleudult	Cane	559	3.67	-0.01	-0.04	0.29	6.85
1121	219924	7493129	Corumbatia	Typic Paleudalf	Cane	540	7.31	-0.09	0.20	1.55	6.76
1122	217139	7493625	Piramboia	Arenic Paleudult	Cane	520	3.36	0.01	-0.12	0.43	7.03
1123	217028	7493214	Piramboia	Arenic Paleudult	Cane	508	4.10	0.04	-0.02	0.50	7.30
1124	217398	7493041	Corumbatia	Typic Eutrochrept	Cane	487	11.2	-0.07	0.03	1.92	7.01
1125	217662	7492955	Corumbatia	Typic Udorthent	Cane	485	1.67	0.02	0.00	0.49	8.16
1126	217269	7491679	Piramboia	Typic Paleudult	Pasture	503	2.98	0.04	-0.01	0.53	7.35
1127	217239	7491765	Corumbatia	Typic Paleudult	Pasture	501	1.20	0.08	0.00	0.17	7.41
1128	217149	7492042	Corumbatia	Typic Paleudult	Pasture	490	4.31	0.10	-0.23	0.51	6.48
1129	217012	7492005	Corumbatia	Typic Udorthent	Pasture	475	3.33	-0.33	-0.04	3.26	10.0
1130	217347	7492130	Corumbatia	Typic Paleudalf	Pasture	489	6.66	0.04	0.00	1.54	6.98
1131	217141	7492266	Corumbatia	Typic Udorthent	Pasture	472	0.28	0.02	-0.05	0.08	8.30
1132	217015	7492364	Corumbatia	Typic Udorthent	Forest	471	0.25	0.00	0.02	0.39	10.6
2013	220088	7492899	Piramboia	Psammentic Paleudult	Cane	558	2.72	0.08	-0.01	0.53	7.50
2014	219559	7493406	Corumbatia	Typic Udorthent	Cane	522	3.84	0.09	-0.06	0.43	6.40
2015	219366	7493641	Corumbatia	Typic Udorthent	Cane	501	8.27	0.23	-0.36	1.36	6.43
2016	219342	7493881	Corumbatia	Typic Paleudalf	Cane	496	5.41	-0.10	0.30	1.23	7.57
2017	219195	7494062	Corumbatia	Typic Paleudalf	Cane	511	3.30	0.11	0.02	0.63	7.10
2018	218946	7494174	Corumbatia	Typic Udorthent	Cane	526	4.19	-0.19	0.08	1.09	8.59
2019	220461	7494374	Corumbatia	Arenic Paleudult	Cane	565	1.50	0.01	0.02	0.28	8.33
2020	219995	7494137	Corumbatia	Typic Udorthent	Forest	540	3.41	0.15	-0.18	0.48	6.89
2021	219773	7494103	Corumbatia	Typic Udorthent	Cane	525	1.92	0.15	-0.03	0.49	7.21
2022	218666	7495244	Piramboia	Arenic Paleudult	Cane	552	4.97	-0.28	0.26	1.09	8.04
2023	218811	7494435	Corumbatia	Typic Paleudalf	Cane	542	1.49	0.18	-0.14	0.18	6.90
2024	218784	7494884	Corumbatia	Arenic Paleudult	Cane	553	6.79	0.09	-0.27	0.78	6.64
2025	216801	7494120	Piramboia	Arenic Paleudult	Cane	539	5.02	0.01	-0.04	0.72	6.50

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope °**	**PLC**	**PRC**	**LS**	**ω**
2026	217172	7493099	Piramboia	Arenic Paleudalf	Cane	507	4.45	0.06	0.07	0.47	6.94
2027	217299	7492877	Piramboia	Typic Eutrochrept	Cane	495	6.69	0.03	-0.10	0.94	6.57
2029	217764	7492063	Corumbatia	Typic Paleudalf	Cane	508	9.99	0.16	-0.39	0.98	6.18
2030	217866	7491812	Piramboia	Typic Paleudalf	Cane	519	6.11	0.01	-0.20	0.67	7.09
3001	215468	7491222	Corumbatia	Typic Udorthent	Pasture	461	0.64	-0.07	0.03	0.71	11.0
3002	215619	7491321	Corumbatia	Alluvium	Pasture	465	0.80	0.00	0.01	0.82	9.80
3003	215682	7491728	Corumbatia	Typic Udipsamment	Forest	465	1.78	0.02	0.01	2.10	8.78
3004	215692	7491662	Corumbatia	Alluvium	Forest	465	1.23	-0.02	0.00	0.85	9.11
3005	215614	7491667	Corumbatia	Typic Udorthent	Forest	465	4.02	0.04	0.12	1.48	7.30
3006	216176	7491944	Corumbatia	Typic Udipsamment	Forest	464	2.50	-0.01	0.39	1.35	8.28
3007	216303	7492167	Corumbatia	Typic Udipsamment	Forest	464	2.54	-0.46	0.28	1.54	9.24
3008	216128	7492548	Corumbatia	Arenic Paleudult	Cane	471	2.10	0.02	0.45	3.42	9.73
3009	216159	7492513	Corumbatia	Arenic Paleudult	Forest	470	1.98	0.04	0.42	2.38	9.00
3010	220047	7494557	Corumbatia	Typic Udorthent	Forest	537	10.48	0.13	0.20	2.38	6.54
3011	220092	7494601	Corumbatia	Typic Udorthent	Forest	542	9.86	-0.21	0.34	1.96	7.66
3012	215268	7491504	Corumbatia	Typic Udorthent	Forest	466	3.58	-0.11	0.46	1.68	7.94
3013	215200	7491521	Corumbatia	Alluvium	Forest	465	0.77	0.02	0.00	1.21	9.25
3014	218591	7493239	Corumbatia	Arenic Endoaquult	Pasture	483	0.78	-0.02	0.00	1.46	11.6
3015	216228	7491925	Corumbatia	Typic Udorthent	Forest	465	1.42	0.03	0.03	1.36	8.84
3016	220428	7493336	Corumbatia	Typic Paleudalf	Forest	516	2.68	-0.17	0.30	2.41	9.56
3017	218746	7493322	Corumbatia	Arenic Endoaquult	Pasture	485	0.88	-0.05	0.01	2.24	11.7
3018	217324	7494051	Corumbatia	Arenic Paleudult	Forest	491	0.54	0.01	0.01	0.28	8.74
3021	219201	7494590	Corumbatia	Typic Udorthent	Pasture	506	2.83	-0.07	0.32	3.92	10.7
3024	215146	7491575	Corumbatia	Typic Udorthent	Forest	465	0.19	-0.16	0.15	4.81	15.04
3026	214986	7492057	Corumbatia	Typic Udorthent	Forest	475	1.41	0.03	-0.02	2.48	9.56
3027	214734	7492097	Piramboia	Arenic Paleudalf	Forest	490	5.53	-0.18	-0.08	3.09	8.96

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
3028	216125	7491836	Corumbatia	Typic Udorthent	Forest	464	0.31	0.00	0.05	0.89	10.3
3029	216322	7492111	Corumbatia	Typic Udorthent	Forest	464	0.23	0.00	0.04	0.44	10.4
3030	215992	7492774	Piramboia	Arenic Paleudult	Forest	474	2.89	-0.58	0.87	6.16	11.2
3032	215814	7491831	Corumbatia	Typic Udipsamment	Forest	465	1.69	0.03	0.04	0.46	8.15
3034	217675	7492635	Corumbatia	Typic Udorthent	Forest	475	1.34	-0.11	0.13	2.11	11.6
3035	219243	7494482	Corumbatia	Typic Paleudalf	Pasture	506	2.58	-0.05	0.46	1.85	8.61
3036	216262	7492489	Corumbatia	Arenic Paleudult	Forest	471	2.02	0.01	0.09	3.17	9.53
3037	216091	7492694	Corumbatia	Arenic Paleudult	Forest	477	7.52	-0.01	0.45	2.97	7.37
3038	217556	7493632	Corumbatia	Typic Udorthent	Forest	485	1.03	-0.01	0.00	1.83	10.1
3039	217515	7494335	Corumbatia	Typic Udorthent	Forest	495	0.96	0.01	0.00	0.95	8.98
3040	221134	7493249	Corumbatia	Typic Udorthent	Pasture	537	5.10	-0.16	0.28	2.80	9.82
3041	219323	7494322	Corumbatia	Typic Udorthent	Pasture	503	2.06	-0.18	0.01	2.66	10.8
3042	219861	7494423	Corumbatia	Typic Udorthent	Forest	516	3.08	-0.22	0.20	4.89	11.4
3043	219983	7494474	Corumbatia	Typic Udorthent	Forest	523	4.57	-0.30	0.05	4.36	10.7
3044	218265	7493684	Corumbatia	Typic Udorthent	Cane	492	0.00	0.00	0.00	0.32	10.7
3045	218572	7493110	Corumbatia	Typic Udorthent	Pasture	485	1.64	0.04	0.01	0.76	8.49
3046	219087	7492522	Corumbatia	Arenic Endoaquult	Pasture	496	0.91	0.01	-0.01	1.89	9.50
3047	219087	7492522	Corumbatia	Arenic Endoaquult	Pasture	496	0.91	0.01	-0.01	1.89	9.50
4001	214645	7491993	Piramboia	Arenic Paleudult	Forest	500	5.62	-0.17	-0.10	1.67	7.84
4002	217166	7493673	Piramboia	Arenic Paleudult	Cane	517	5.00	0.06	0.01	0.75	6.88
4003	214957	7491344	Corumbatia	Typic Udorthent	Cane	485	2.77	0.01	-0.02	0.53	7.17
4004	215724	7491912	Corumbatia	Typic Udipsamment	Cane	474	6.85	0.13	-0.32	1.53	6.88
4005	216112	7492041	Corumbatia	Typic Paleudalf	Cane	475	4.37	0.01	-0.10	0.75	7.28
4006	220234	7492829	Piramboia	Psammentic Paleudult	Cane	556	4.33	0.00	-0.04	0.60	7.00
4007	215273	7492671	Piramboia	Arenic Paleudult	Cane	513	4.39	0.00	-0.14	0.49	7.14
4008	220489	7494033	Corumbatia	Typic Udorthent	Forest	542	3.27	0.09	0.22	0.75	6.72

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
4009	214714	7492245	Piramboia	Psammentic Paleudult	Cane	506	4.57	0.03	-0.07	0.86	7.35
4010	216457	7493658	Piramboia	Arenic Paleudult	Cane	531	2.23	-0.10	-0.03	0.53	8.53
4011	219705	7494845	Corumbatia	Typic Paleudalf	Pasture	549	7.24	-0.27	-0.02	2.20	8.22
4012	216879	7493065	Corumbatia	Typic Dystrochrept	Forest	485	10.45	0.05	-0.13	1.84	7.04
4013	215907	7491444	Corumbatia	Typic Paleudult	Pasture	485	3.56	0.12	-0.02	0.58	6.72
4014	220398	7493926	Corumbatia	Typic Udorthent	Forest	529	7.52	0.08	-0.10	1.53	6.35
4015	218103	7493138	Corumbatia	Typic Kandiaqualf	Forest	482	0.63	0.03	-0.01	0.87	9.28
4016	218330	7492925	Corumbatia	Typic Udorthent	Pasture	494	5.19	0.08	0.04	0.97	6.95
4017	218912	7492529	Corumbatia	Typic Udorthent	Cane	502	7.21	0.22	-0.08	1.32	6.77
4018	220638	7494212	Corumbatia	Arenic Paleudult	Pasture	554	4.78	-0.10	-0.01	1.33	8.97
4019	218568	7494902	Corumbatia	Arenic Paleudult	Cane	557	5.49	0.07	-0.08	0.70	6.36
4020	217827	7493543	Corumbatia	Typic Udorthent	Pasture	496	7.47	-0.09	-0.05	1.41	6.95
4021	219771	7491467	Corumbatia	n.a.	Cane	555	0.96	-0.04	0.01	0.14	7.70
4022	216756	7491841	Corumbatia	Typic Paleudult	Pasture	484	5.40	-0.01	0.10	1.33	7.12
4023	217882	7492926	Corumbatia	Typic Udorthent	Forest	482	2.56	0.09	0.11	0.65	7.62
4024	219267	7492501	Corumbatia	Arenic Endoaquult	Pasture	503	5.44	0.07	-0.05	2.02	8.52
4025	219909	7492655	Piramboia	Typic Paleudalf	Cane	551	5.32	0.04	-0.01	1.65	7.07
4026	218109	7494173	Corumbatia	Typic Paleudalf	Cane	531	1.81	0.12	-0.02	0.28	7.21
4027	218619	7492037	Piramboia	Typic Udorthent	Cane	528	5.18	0.02	-0.36	0.47	6.36
4028	219254	7494199	Corumbatia	Typic Paleudalf	Cane	505	2.31	-0.07	0.01	2.19	10.7
4029	218694	7491833	Piramboia	Typic Paleudalf	Cane	532	0.81	0.06	-0.05	0.11	7.45
5001	216293	7492949	Serra Geral	Arenic Paleudult	Cane	514	0.12	0.00	-0.02	0.09	9.36
5002	216271	7492926	Serra Geral	Arenic Paleudult	Cane	514	0.00	0.00	0.00	0.16	10.6
5003	216251	7492904	Serra Geral	Arenic Paleudult	Cane	514	0.00	0.00	0.00	0.07	10.0
5004	216231	7492882	Corumbatia	Arenic Paleudult	Cane	511	7.02	0.00	0.05	0.80	6.16
5005	216211	7492860	Corumbatia	Arenic Paleudult	Cane	508	6.20	0.06	0.00	1.06	6.64

Table A.9 continued

Sample	Easting m	Northing m	Geo	Soil	Use	Elevation m	Slope º	PLC	PRC	LS	ω
5006	216193	7492838	Corumbatia	Arenic Paleudult	Cane	505	5.98	0.09	-0.02	1.24	6.92
5007	216173	7492815	Corumbatia	Arenic Paleudult	Cane	502	5.81	0.08	-0.14	1.33	7.05
5008	216151	7492793	Corumbatia	Arenic Paleudult	Cane	498	10.73	-0.02	-0.08	1.85	6.65
5009	216131	7492771	Corumbatia	Arenic Paleudult	Cane	492	10.04	-0.01	-0.04	2.26	6.89
5010	216111	7492749	Corumbatia	Arenic Paleudult	Cane	487	11.91	0.12	0.23	2.73	6.85
5011	216100	7492735	Corumbatia	Arenic Paleudult	Cane	482	8.39	0.21	-0.14	2.70	7.17
5012	216317	7492930	Serra Geral	Arenic Paleudult	Cane	514	0.16	-0.12	-0.16	0.07	8.86
5013	216297	7492909	Serra Geral	Arenic Paleudult	Cane	514	0.00	0.00	0.00	0.06	9.90
5014	216277	7492886	Serra Geral	Arenic Paleudult	Cane	514	0.04	0.00	-0.01	0.06	10.6
5015	216257	7492864	Corumbatia	Arenic Paleudult	Cane	513	6.50	0.03	-0.21	0.48	6.15
5016	216237	7492842	Corumbatia	Arenic Paleudult	Cane	507	6.51	0.10	0.00	1.07	6.57
5017	216217	7492820	Corumbatia	Arenic Paleudult	Cane	504	6.34	0.08	-0.06	1.27	6.79
5018	216197	7492798	Corumbatia	Arenic Paleudult	Cane	501	6.81	-0.09	-0.06	1.51	7.00
5019	216177	7492776	Corumbatia	Arenic Paleudult	Cane	497	9.63	-0.01	-0.02	1.92	6.82
5020	216157	7492754	Corumbatia	Arenic Paleudult	Cane	492	10.67	0.10	-0.29	2.28	6.74
5021	216137	7492732	Corumbatia	Arenic Paleudult	Cane	486	12.64	0.09	0.24	2.83	6.60
5022	216125	7492719	Corumbatia	Arenic Paleudult	Cane	482	9.60	-0.03	0.34	3.09	7.24
5023	216321	7492891	Serra Geral	Arenic Paleudult	Cane	514	0.00	0.00	0.00	0.06	9.90
5024	216301	7492869	Serra Geral	Arenic Paleudult	Cane	514	1.35	0.00	-0.24	0.15	6.75
5025	216282	7492846	Corumbatia	Arenic Paleudult	Cane	512	6.61	-0.01	-0.07	0.60	6.21
5026	216263	7492824	Corumbatia	Arenic Paleudult	Cane	509	6.90	0.05	-0.01	0.99	6.48
5027	216242	7492802	Corumbatia	Arenic Paleudult	Cane	504	6.49	0.06	-0.04	1.38	6.87
5028	216367	7492895	Serra Geral	Arenic Paleudult	Cane	514	5.34	0.41	-0.91	0.54	5.37
5029	216346	7492874	Serra Geral	Arenic Paleudult	Cane	514	0.00	0.00	0.00	0.06	9.90
5030	216326	7492851	Serra Geral	Arenic Paleudult	Cane	514	1.61	0.00	-0.28	0.17	6.56
5031	216306	7492830	Corumbatia	Arenic Paleudult	Cane	512	6.26	0.01	-0.08	0.65	6.06

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope °**	**PLC**	**PRC**	**LS**	**ω**
5032	216287	7492808	Corumbatia	Arenic Paleudult	Cane	509	7.82	0.04	-0.10	1.14	6.28
5033	216267	7492785	Corumbatia	Arenic Paleudult	Cane	505	6.41	0.00	0.17	1.38	6.84
5034	216247	7492763	Corumbatia	Arenic Paleudult	Cane	501	4.46	-0.09	-0.03	1.48	7.74
5035	216227	7492741	Corumbatia	Arenic Paleudult	Forest	499	7.31	-0.16	-0.21	1.70	7.55
5036	216207	7492719	Corumbatia	Arenic Paleudult	Forest	494	12.39	-0.30	-0.73	2.09	7.22
5037	216187	7492696	Corumbatia	Arenic Paleudult	Forest	488	13.56	-0.13	0.49	2.53	7.13
5038	216167	7492674	Corumbatia	Arenic Paleudult	Cane	484	9.62	-0.04	0.25	2.70	7.29
5039	216391	7492891	Serra Geral	Arenic Paleudult	Cane	511	8.54	-0.17	0.06	0.91	5.80
5040	216371	7492869	Serra Geral	Arenic Paleudult	Cane	514	0.97	0.00	-0.17	0.12	7.09
5041	216351	7492846	Serra Geral	Arenic Paleudult	Cane	514	0.90	0.00	-0.16	0.12	7.15
5042	216333	7492823	Corumbatia	Arenic Paleudult	Cane	511	6.79	0.03	-0.03	0.84	6.19
5043	216313	7492801	Corumbatia	Arenic Paleudult	Cane	507	7.26	0.01	0.14	1.27	6.51
5044	216295	7492780	Corumbatia	Arenic Paleudult	Cane	504	4.80	-0.02	0.12	1.37	7.26
5045	216276	7492760	Corumbatia	Arenic Paleudult	Cane	502	4.00	-0.08	0.04	1.39	7.75
5046	216256	7492736	Corumbatia	Arenic Paleudult	Cane	500	4.98	-0.04	-0.20	1.41	7.69
5047	216237	7492713	Corumbatia	Arenic Paleudult	Cane	497	7.79	-0.12	-0.15	1.60	7.39
5048	216217	7492691	Corumbatia	Arenic Paleudult	Cane	494	12.49	0.06	-0.69	1.90	6.74
5049	216197	7492669	Corumbatia	Arenic Paleudult	Cane	488	13.05	0.06	0.37	2.35	6.48
5050	216177	7492645	Corumbatia	Arenic Paleudult	Cane	483	8.98	0.05	0.26	2.52	6.68
5051	216358	7492816	Corumbatia	Arenic Paleudult	Cane	511	6.45	0.01	0.04	0.75	6.17
5052	216339	7492794	Corumbatia	Arenic Paleudult	Cane	508	6.56	0.01	0.05	1.10	6.52
5053	216320	7492771	Corumbatia	Arenic Paleudult	Cane	505	5.41	-0.01	0.15	1.30	7.02
5054	216301	7492748	Corumbatia	Arenic Paleudult	Cane	503	3.65	0.02	0.03	1.25	7.60
5055	216283	7492724	Corumbatia	Arenic Paleudult	Cane	502	3.67	0.01	-0.05	1.20	7.75
5056	216264	7492701	Corumbatia	Arenic Paleudult	Cane	500	4.48	0.22	-0.21	0.82	6.89
5057	216245	7492678	Corumbatia	Arenic Paleudult	Cane	498	5.27	0.15	0.02	0.96	6.80

Table A.9 continued

Sample	**Easting m**	**Northing m**	**Geo**	**Soil**	**Use**	**Elevation m**	**Slope º**	**PLC**	**PRC**	**LS**	**ω**
5058	216226	7492654	Corumbatia	Arenic Paleudult	Cane	495	7.22	0.27	-0.15	1.17	6.40
5070	216119	7493176	Piramboia	Arenic Paleudult	Cane	529	5.34	0.31	-0.31	0.66	6.46
5071	216072	7493113	Piramboia	Typic Dystrochrept	Cane	521	5.55	-0.03	-0.17	1.11	6.76
5072	215953	7493034	Piramboia	Arenic Paleudult	Cane	501	10.63	-0.05	-0.67	2.58	7.04
5073	215873	7493276	Piramboia	Arenic Paleudult	Cane	530	1.69	0.03	-0.33	0.18	6.52
5074	215867	7493219	Piramboia	Typic Dystrochrept	Forest	520	10.89	-0.03	0.03	2.39	6.11
5075	215876	7493079	Piramboia	Arenic Paleudult	Forest	496	11.35	0.03	-0.23	4.28	7.89
5076	215876	7493079	Piramboia	Arenic Paleudult	Forest	496	11.35	0.03	-0.23	4.28	7.89
5077	215494	7493032	Piramboia	Arenic Paleudult	Cane	529	10.68	0.14	-0.42	1.57	6.53
5078	215682	7493020	Piramboia	Arenic Paleudult	Forest	499	12.08	-0.05	-0.03	4.19	7.20
5079	215744	7492838	Piramboia	Arenic Paleudult	Cane	503	6.10	0.06	-0.04	1.34	6.62
5080	215783	7492873	Piramboia	Arenic Paleudult	Cane	496	15.26	-0.14	0.21	2.68	5.94
5081	215851	7492882	Piramboia	Arenic Paleudult	Forest	482	6.16	-0.21	0.59	3.77	7.90
5082	215844	7492536	Piramboia	Arenic Paleudult	Cane	504	1.90	0.00	-0.33	0.20	6.40
5083	215929	7492571	Piramboia	Arenic Paleudult	Cane	494	10.55	0.07	-0.33	1.77	6.41
5084	216021	7492635	Corumbatia	Arenic Paleudult	Cane	477	4.75	0.04	0.04	2.81	7.81
5085	216050	7492451	Corumbatia	Arenic Paleudult	Cane	483	6.97	0.06	0.19	2.27	7.17
5086	216095	7492512	Corumbatia	Arenic Paleudult	Cane	475	8.17	-0.02	-0.25	2.58	7.44
5087	216134	7492508	Corumbatia	Arenic Paleudult	Cane	471	5.31	0.01	0.44	2.44	7.90
5088	216199	7492344	Corumbatia	Arenic Paleudult	Cane	478	5.77	0.07	-0.01	1.29	6.83
5089	216241	7492363	Corumbatia	Arenic Paleudult	Cane	474	7.40	0.44	-0.16	1.42	6.39
6001	216008	7493029	Piramboia	Arenic Paleudult	Cane	507	5.46	0.03	-0.01	2.03	7.42
6002	215959	7493120	Piramboia	Arenic Paleudult	Forest	504	8.99	-0.11	0.11	3.16	8.00
6003	216062	7493134	Piramboia	Typic Dystrochrept	Forest	521	6.60	0.15	-0.26	1.27	6.50
6004	215880	7492938	Piramboia	Arenic Paleudult	Forest	483	3.06	-0.15	0.17	2.13	8.08
6005	217315	7495059	Piramboia	Arenic Paleudult	Cane	542	4.00	0.09	-0.01	0.45	6.46

Table A.9 continued

Sample	Easting m	Northing m	Geo	Soil	Use	Elevation m	Slope °	PLC	PRC	LS	ω
6006	217234	7495022	Piramboia	Arenic Paleudult	Forest	531	8.89	-0.17	0.24	2.05	7.02
6007	217274	7495098	Piramboia	Arenic Paleudult	Pasture	544	4.36	0.10	-0.42	0.41	6.48
6008	217382	7494709	Piramboia	Mollic Paleudalf	Forest	513	7.25	0.01	0.10	1.32	6.55
6009	218824	7495378	Piramboia	Typic Udorthent	Cane	531	6.35	-0.48	0.22	5.94	10.5
6010	218580	7495423	Piramboia	Arenic Paleudult	Forest	559	3.60	-0.05	-0.07	0.38	6.33
6011	218916	7495525	Piramboia	Typic Udorthent	Forest	547	10.12	-0.09	-0.19	2.21	7.33
6012	219054	7495431	Piramboia	Arenic Paleudalf	Cane	540	17.25	1.18	-1.21	2.87	5.24
6013	218958	7495420	Piramboia	Typic Udorthent	Forest	526	7.50	-0.60	1.18	4.71	9.49
6014	219316	7493831	Corumbatia	Typic Paleudalf	Cane	495	5.33	0.02	0.12	1.18	7.73
6015	219350	7493778	Corumbatia	Typic Paleudalf	Forest	492	0.00	0.00	0.00	0.53	11.3
6016	219256	7492682	Corumbatia	Typic Eutrochrept	Cane	523	5.21	0.18	-0.16	0.67	6.35
6017	219298	7492634	Corumbatia	Typic Udorthent	Pasture	517	9.96	0.02	-0.12	1.55	6.45
6018	219128	7492660	Corumbatia	Typic Udorthent	Pasture	510	9.66	0.07	0.03	2.06	6.51
6019	219350	7492658	Corumbatia	Typic Udorthent	Pasture	517	8.94	0.04	0.21	1.62	7.07
6020	220016	7492671	Piramboia	Psammentic Paleudult	Cane	555	8.80	0.10	0.40	1.81	6.15
6021	219964	7492528	Piramboia	Typic Udorthent	Forest	541	8.41	0.56	-0.48	1.67	6.30
6022	220038	7492607	Piramboia	Typic Udorthent	Forest	547	9.52	0.01	0.08	2.17	6.59
6023	219479	7492399	Corumbatia	Typic Udorthent	Cane	513	4.57	0.06	-0.03	0.96	7.20
6024	219538	7492316	Corumbatia	Typic Udorthent	Forest	519	3.37	0.03	0.00	1.11	7.52
6025	219584	7492234	Corumbatia	Typic Udorthent	Forest	524	7.84	0.10	-0.09	1.23	6.86
6026	219416	7492344	Corumbatia	Typic Udorthent	Forest	509	8.63	0.17	-0.33	1.31	6.67
6027	219442	7492223	Corumbatia	Typic Udorthent	Forest	512	0.54	0.01	-0.12	0.09	7.66
6028	215635	7491199	Corumbatia	Typic Udorthent	Pasture	465	1.41	-0.08	0.02	1.09	9.21
6029	215645	7491291	Corumbatia	Alluvium	Pasture	465	0.72	-0.02	0.01	0.76	9.68
6030	215611	7491348	Corumbatia	Alluvium	Pasture	465	0.82	-0.01	0.00	1.12	10.1
6031	215556	7491347	Corumbatia	Alluvium	Pasture	464	1.19	0.01	0.11	0.68	8.44

PLC = plane curvature; PRC = profile curvature; n.a. = not analysed/not available

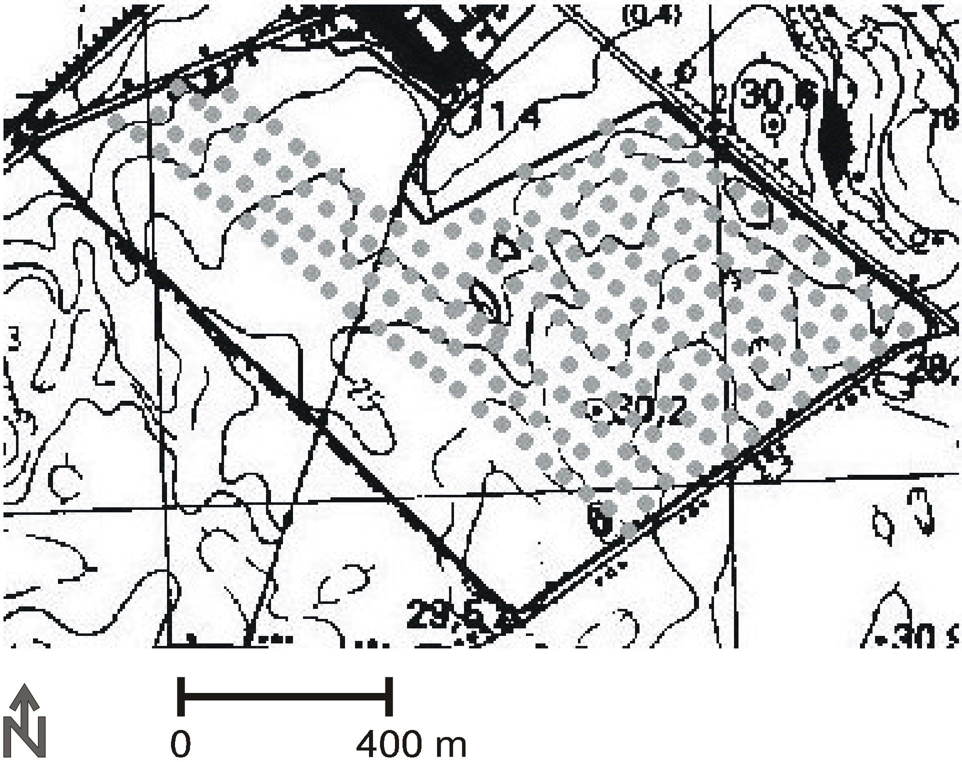

Fig. A.1: Location of sampling points at the Kassow study site (E12°06’, N53°10’).

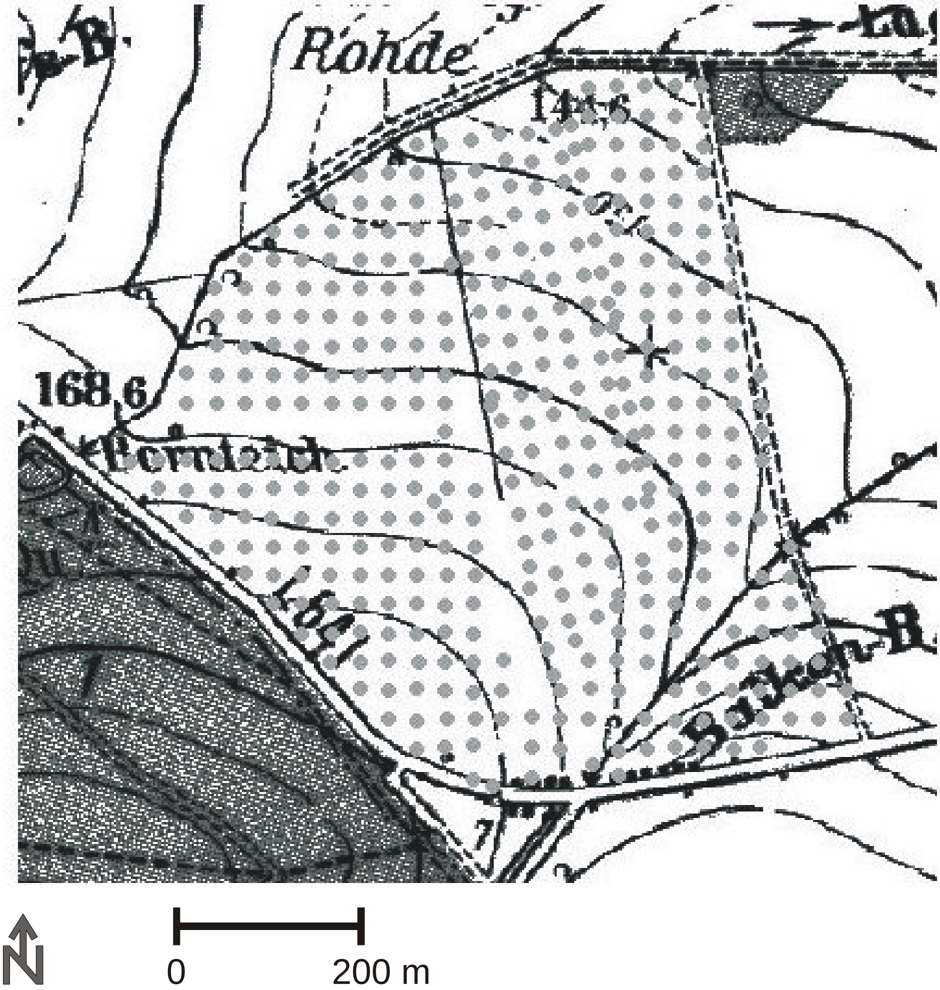

Fig. A.2: Location of sampling points at the Warberg study site (E10°54’, N52°10’).

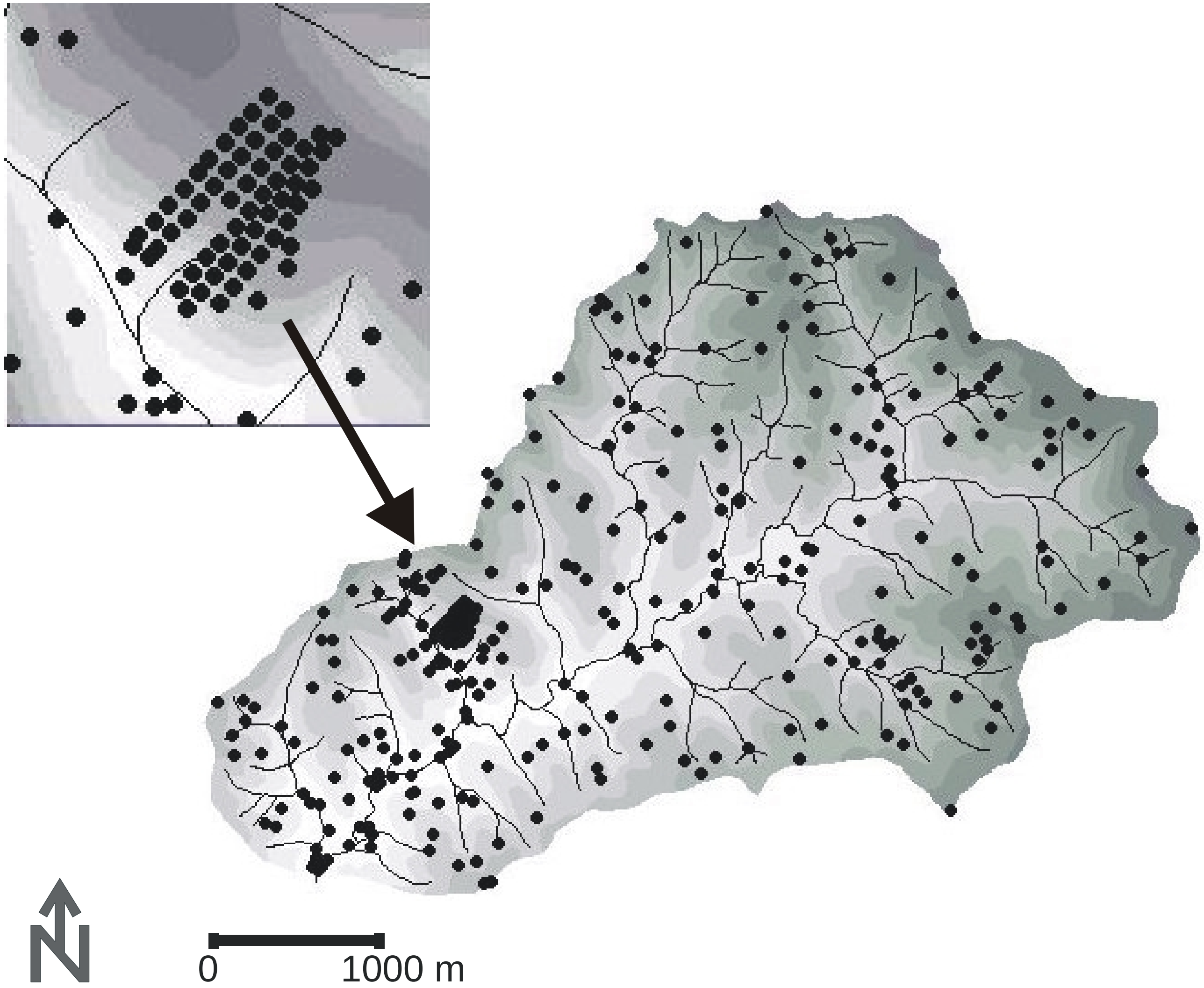

Fig. A.3: Location of sampling points at the Ceveiro study site (W74°47’, S22°40’).

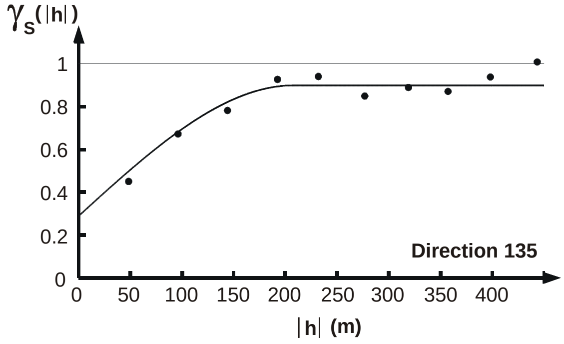

Fig. A.4: Standardised semivariogram for AR-P (135°) in Kassow (E 12°06’; N 53°10’).

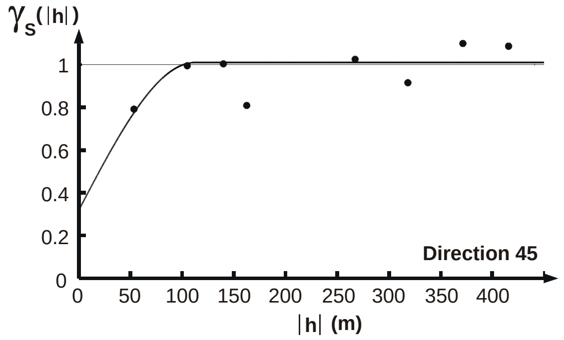

Fig. A.5: Standardised semivariogram for AR-P (45°) in Kassow (E 12°06’; N 53°10’).

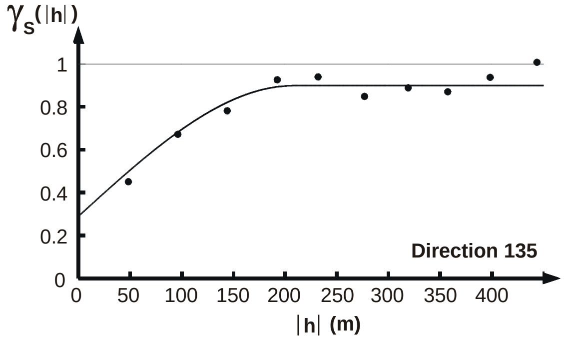

Fig. A.6: Standardised semivariogram for WH-P (135°) in Kassow (E 12°06’; N 53°10’).

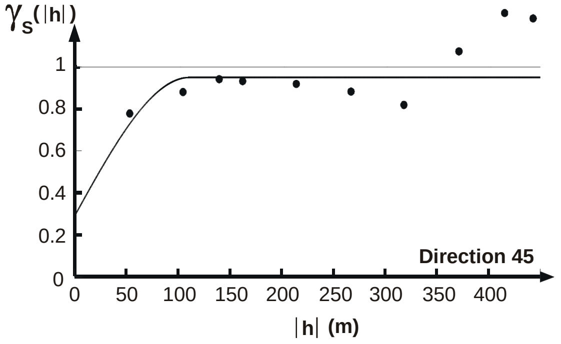

Fig. A.7: Standardised semivariogram for WH-P (45°) in Kassow (E 12°06’; N 53°10’).

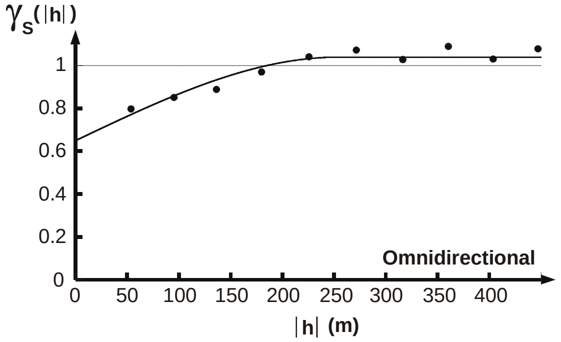

Fig. A.8: Omnidirectional standardised semivariogram for AAC-P in Kassow (E 12°06’; N 53°10’).

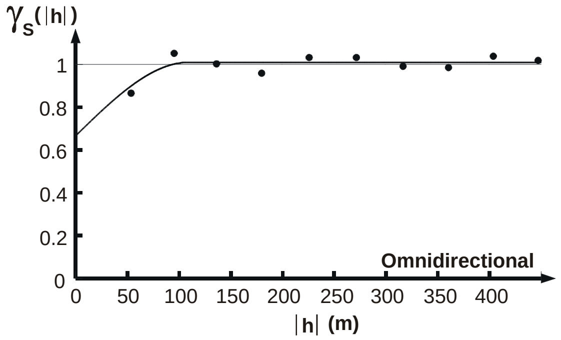

Fig. A.9: Omnidirectional standardised semivariogram for $CaCl_2$-P in Kassow (E 12°06’; N 53°10’).

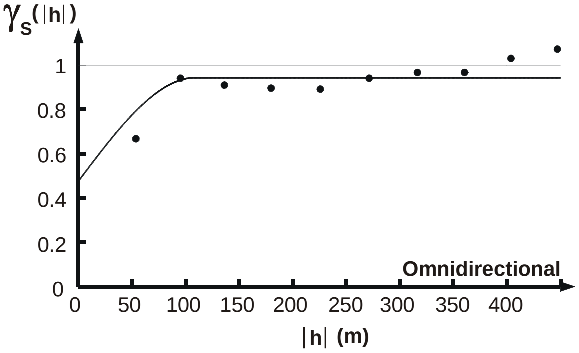

Fig. A.10: Omnidirectional standardised indicator variogram for loamy sand in Kassow (E 12°06'; N 53°10').

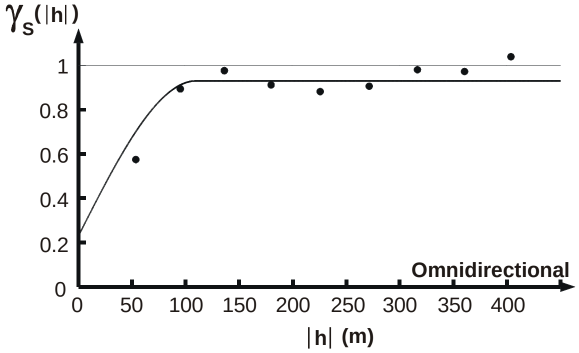

Fig. A.13: Omnidirectional standardised indicator variogram for high loamy sand in Kassow (E 12°06'; N 53°10').

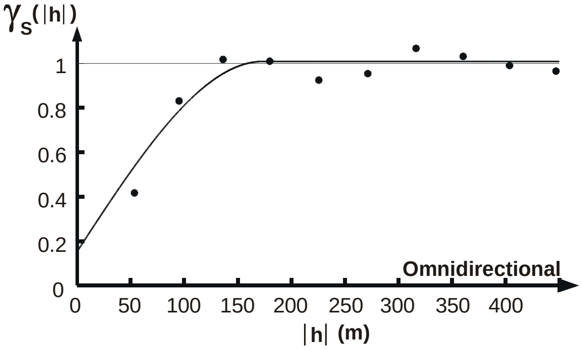

Fig. A.11: Omnidirectional standardised indicator variogram for sandy loam in Kassow (E 12°06'; N 53°10').

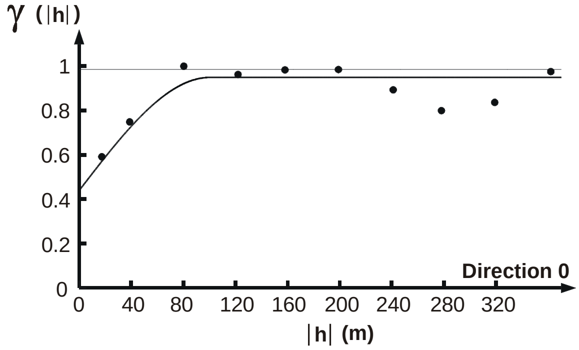

Fig. A.14: Local standardised semi-variogram for AR-P (0°) in Warberg (E 10°54'; N 52°10').

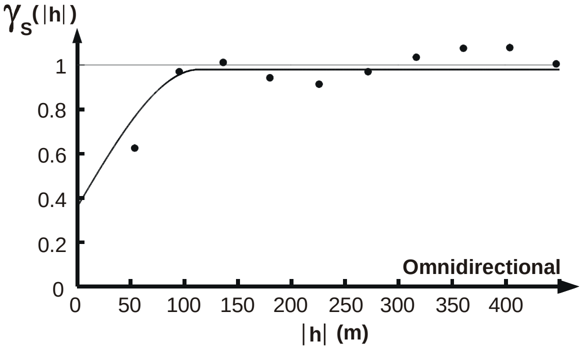

Fig. A.12: Omnidirectional standardised indicator variogram for medium sandy loam in Kassow (E 12°06'; N 53°10').

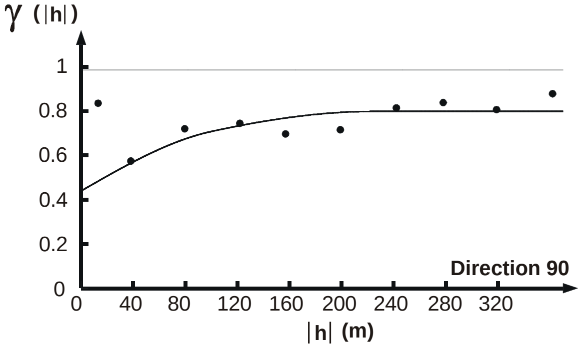

Fig. A.15: Local standardised semi-variogram for AR-P (90°) in Warberg (E 10°54'; N 52°10').

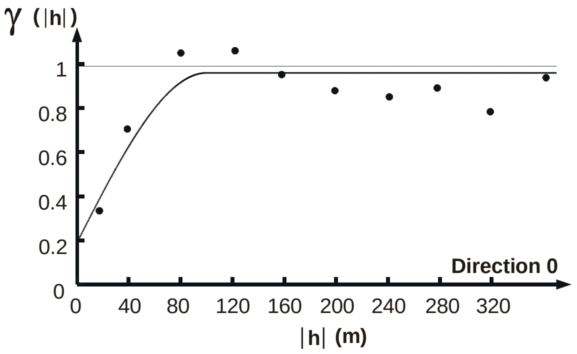

Fig. A.16: Local standardised semivariogram for WH-P (0°) in Warberg (E 10°54'; N 52°10').

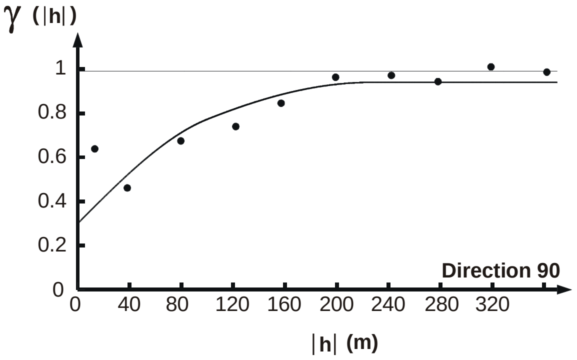

Fig. A.19: Local standardised semivariogram for AAC-P (90°) in Warberg (E 10°54'; N 52°10').

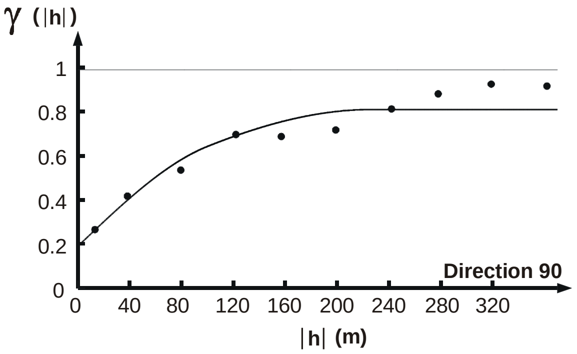

Fig. A.17: Local standardised semivariogram for WH-P (90°) in Warberg (E 10°54'; N 52°10').

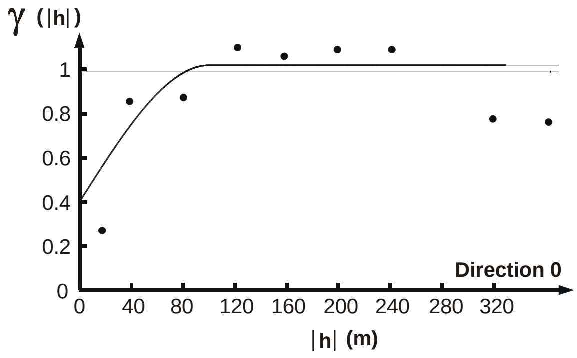

Fig. A.20: Local standardised semivariogram for $CaCl_2$-P (0°) in Warberg (E 10°54'; N 52°10').

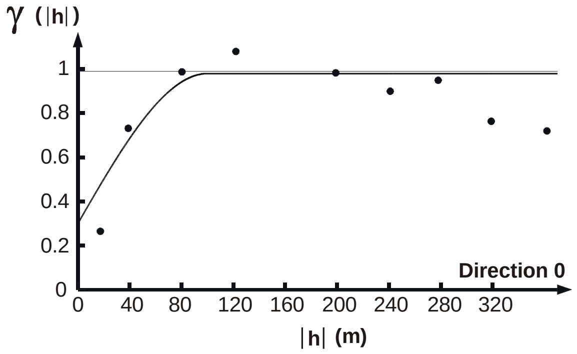

Fig. A.18: Local standardised semivariogram for AAC-P (0°) in Warberg (E 10°54'; N 52°10').

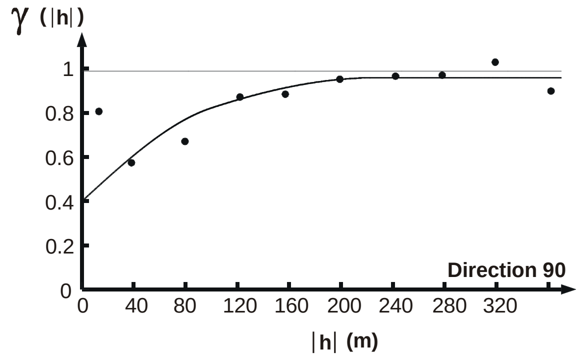

Fig. A.21: Local standardised semivariogram for $CaCl_2$-P (90°) in Warberg (E 10°54'; N 52°10').

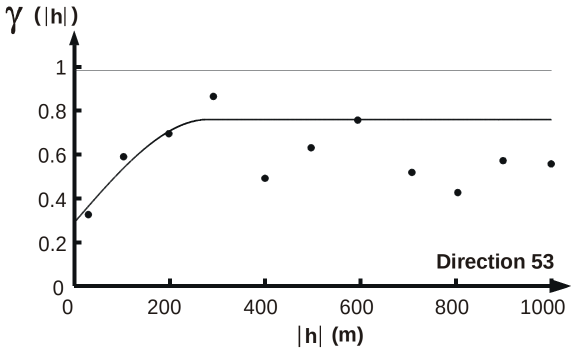

Fig. A.22: Semivariogram for rank normalised AR-P (53°) in Ceveiro (W 47°47'; S 22°40').

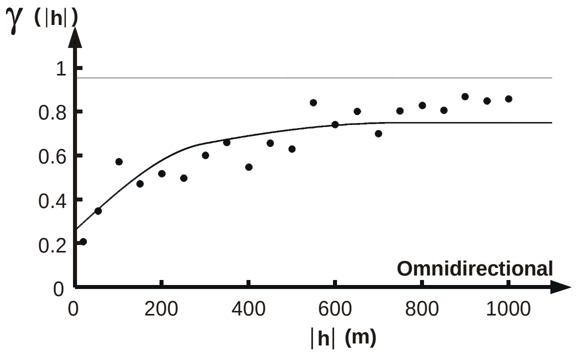

Fig. A.25: Omnidirectional semivariogram for rank normalised Resin-P in Ceveiro (W 47°47'; S 22°40').

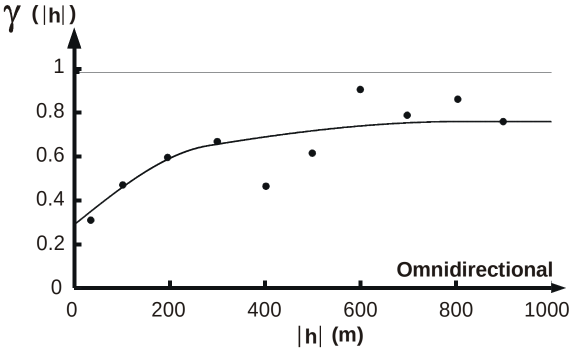

Fig. A.23: Omnidirectional semivariogram for rank normalised AR-P in Ceveiro (W 47°47'; S 22°40').

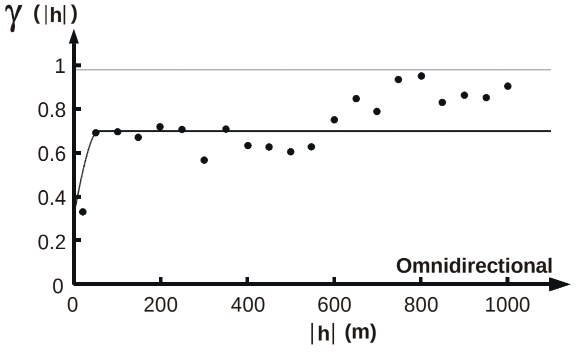

Fig. A.26: Omnidirectional semivariogram for rank normalised WH-P in Ceveiro (W 47°47'; S 22°40').

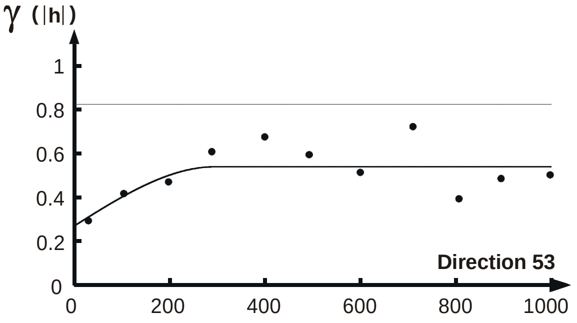

Fig. A.24: Semivariogram for rank normalised Resin-P (53°) in Ceveiro (W 47°47'; S 22°40').

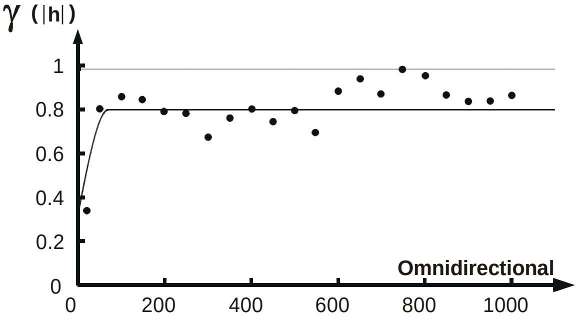

Fig. A.27: Omnidirectional semivariogram for rank normalised AAC-P in Ceveiro (W 47°47'; S 22°40').

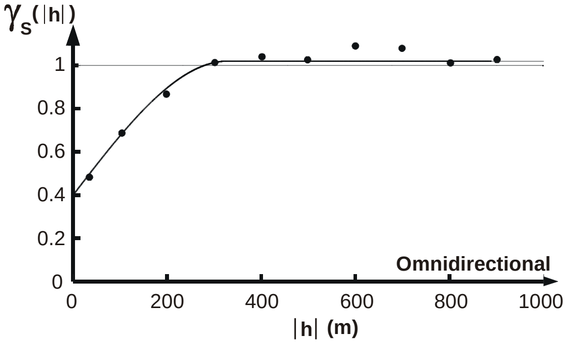

Fig. A.28: Omnidirectional standardised indicator variogram for sugar cane in Ceveiro (W 47°47’; S 22°40’).

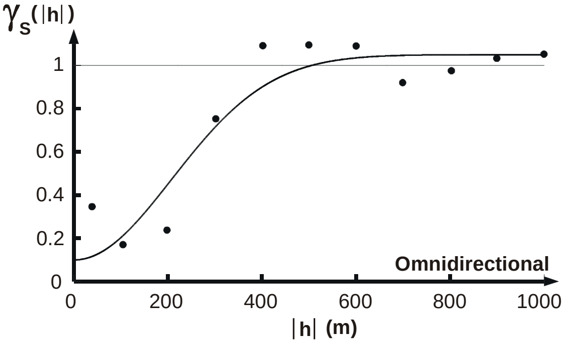

Fig. A.31: Omnidirectional standardised indicator variogram for the Piramboia formation in Ceveiro (W 47°47’; S 22°40’).

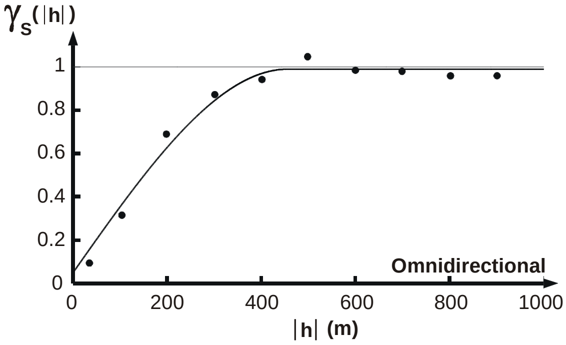

Fig. A.29: Omnidirectional standardised indicator variogram for pasture in Ceveiro (W 47°47’; S 22°40’).

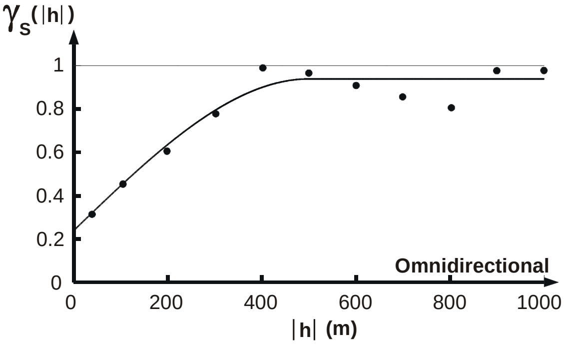

Fig. A.32: Omnidirectional standardised indicator variogram for the Corumbatai formation in Ceveiro (W 47°47’; S 22°40’).

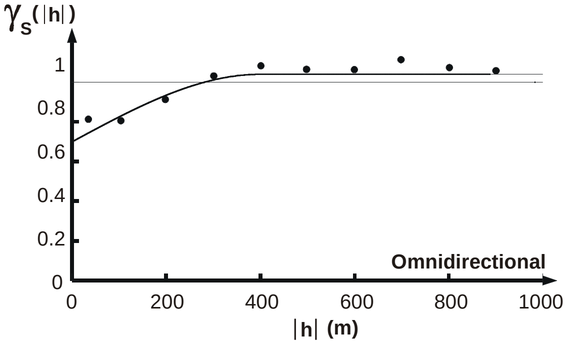

Fig. A.30: Omnidirectional standardised indicator variogram for forest in Ceveiro (W 47°47’; S 22°40’).

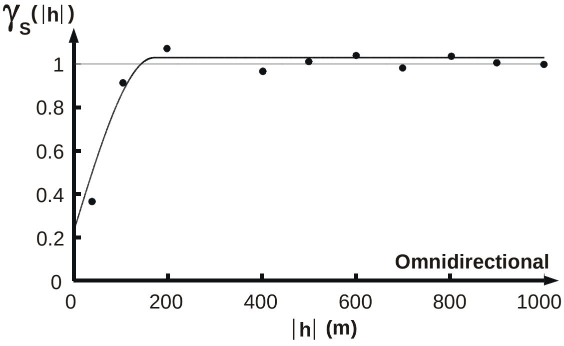

Fig. A.33: Omnidirectional standardised indicator variogram for the Serra Geral Formation in Ceveiro (W 47°47’; S 22°40’).

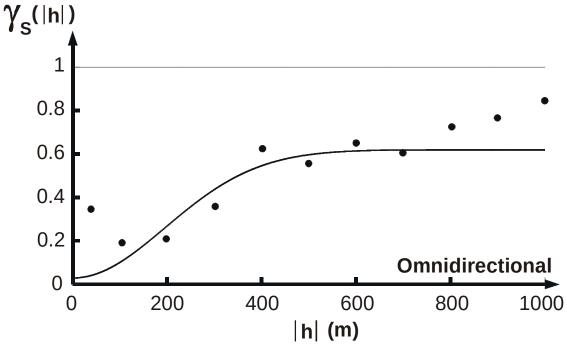

Fig. A.34: Omnidirectional standardised indicator variogram for the Arenic Paleudult in Ceveiro (W 47°47'; S 22°40').

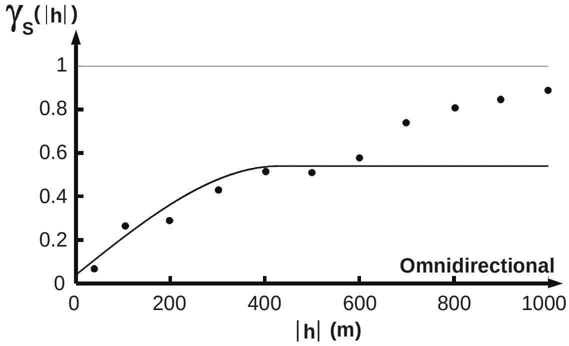

Fig. A.35: Omnidirectional standardised indicator variogram for the Typic Udorthent in Ceveiro (W 47°47'; S 22°40').

Tab. A.10: Results of the rotated component matrix for the three study sites, Kassow, Warberg, Ceveiro.

	Kassow		**Warberg**			**Ceveiro**			
	Cambisol		**Luvisol**			**Paleudult**		**Udorthent**	
	PC1	**PC2**	**PC1**	**PC2**	**PC3**	**PC1**	**PC2**	**PC1**	**PC2**
pH$_{CaCl2}$	0.36	0.71	0.22	0.52	0.32	0.40	0.20	0.46	0.20
CaCO$_3$	-0.05	0.66	0.88	0.10	-0.02				
C$_{tot}$	0.39	0.70	0.88	0.15	0.15	0.18	0.17	0.31	0.89
Clay	-0.04	0.29	0.21	0.87	-0.09	0.86	-0.02	0.79	0.11
Fe			-0.01	0.82	0.02	0.95	-0.10	0.88	0.14
Zn	0.73	0.39	0.36	0.52	-0.06	0.93	0.00	0.80	0.14
P$_{CaCl2}$	0.68	-0.48	0.31	-0.34	0.77				
P$_{Resin}$						0.16	0.94	0.29	0.04
P$_{AAC}$	0.82	0.06	-0.04	0.18	0.92	-0.03	0.96	0.05	0.95
P$_{WH}$	0.91	0.09	0.70	0.42	0.45	0.03	0.94	0.21	0.90
P$_{AR}$	0.85	0.07	0.58	0.54	0.39	0.78	0.49	0.75	0.52
explained Variance	41 %	19 %	42 %	18 %	12 %	47 %	18 %	42 %	29 %
latent Variable	P input	Application of lime	Secondary Ca-phosphates	Adsorption capacity	High pH induced decreased extraction force of AAC and CaCl$_2$	Adsorption capacity	P input	Adsorption capacity	P input

Tab. A.11: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of AR-P for the Kassow study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**St.Error**	**DF**	**t-Value**	**p**
Intercept	630.88	39.27	186	16.06	<.0001
Texture1	-10.62	19.55	186	-0.54	0.588
Texture 2	-47.78	26.47	186	-1.80	0.073
Texture 3	-27.25	16.13	186	-1.69	0.093
Texture 4	0		186		

Tab. A.12: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of WH-P for the Kassow study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**St.Error**	**DF**	**t-Value**	**p**
Intercept	373.95	31.44	186	11.89	<.0001
Texture1	-6.08	16.91	186	-0.36	0.720
Texture 2	-53.22	22.93	186	-2.32	0.021
Texture 3	27.38	14.14	186	-1.94	0.054
Texture 4	0		186		

Tab. A.13: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of AAC-P for the Kassow study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**St.Error**	**DF**	**t-Value**	**p**
Intercept	73.23	7.20	186	10.17	<.0001
Texture1	-2.68	8.33	186	-0.32	0.748
Texture 2	-18.07	11.30	186	-1.60	0.112
Texture 3	-2.98	7.12	186	-0.42	0.676
Texture 4	0	-	186	-	-

Tab. A.14: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of $CaCl_2$-P for the Kassow study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**St.Error**	**DF**	**t-Value**	**p**
Intercept	6.11	0.41	186	14.83	<.0001
Texture1	-1.12	0.43	186	-2.63	0.009
Texture 2	-1.91	0.57	186	3.33	0.001
Texture 3	0.42	0.36	186	-1.18	0.238
Texture 4	0	-	186	-	-

Tab. A.15: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of AR-P for the Warberg study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**Error**	**DF**	**t**	**p**
Intercept	823.99	173.87	383	4.74	<.0001
BB	-193.56	120.85	383	-1.60	0.110
GB	-81.41	64.89	383	-1.25	0.210
M1	-112.96	37.95	383	-2.98	0.003
M2	-138.48	32.37	383	-4.28	<.0001
M3	0.00	-	-	-	-
L4	-166.56	149.10	383	-1.12	0.265
L5	-129.13	91.42	383	-1.41	0.159
LT4	-136.53	73.85	383	-1.85	0.065
LT5	96.72	150.91	383	0.64	0.522
T4	0.00	-	-	-	-
BB x L4	180.36	174.83	383	1.03	0.303
GB x L4	67.25	136.06	383	0.49	0.621
GB x L5	29.22	136.98	383	0.21	0.831
M1 x L4	-43.11	126.11	383	-0.34	0.733
M2 x L4	78.61	123.68	383	0.64	0.525

Tab. A.16: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of WH-P for the Warberg study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**Error**	**DF**	**t**	**p**
Intercept	483.76	146.70	382	3.30	0.001
BB	-31.84	91.01	382	-0.35	0.727
GB	-15.42	49.01	382	-0.31	0.753
M1	-72.04	28.85	382	-2.50	0.013
M2	-44.80	24.38	382	-1.84	0.067
M3	0.00	-	-	-	-
L4	-73.78	112.11	382	-0.66	0.511
L5	-86.80	68.53	382	-1.27	0.206
LT4	-22.67	55.57	382	-0.41	0.684
LT5	77.59	113.49	382	0.68	0.495
T4	0.00	-	-	-	-
BB x L4	109.06	131.85	382	0.83	0.409
GB x L4	-7.48	102.31	382	-0.07	0.942
GB x L5	72.08	103.10	382	0.70	0.485
M1 x L4	-13.68	95.11	382	-0.14	0.886
M3 x L4	4.96	93.03	382	0.05	0.958

Tab. A.17: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of $CaCl_2$-P for the Warberg study site

Effect	**Solution for Fixed Effects**				
	Estimate	**Error**	**DF**	**t**	**p**
Intercept	5.09	0.87	384	5.86	<.0001
BB	0.14	0.46	384	0.30	0.765
GB	-0.54	0.25	384	-2.14	0.033
M1	-0.79	0.15	384	-5.26	<.0001
M2	-0.39	0.14	384	-2.83	0.005
M3	0.00	-	-	-	-
L4	-0.56	0.57	384	-1.00	0.320
L5	-0.10	0.35	384	-0.27	0.784
LT4	-0.02	0.28	384	-0.08	0.938
LT5	0.10	0.58	384	0.18	0.856
T4	0.00	-	-	-	-
BB x L4	0.56	0.66	384	0.85	0.397
GB x L4	0.45	0.51	384	0.87	0.386
GB x L5	0.12	0.52	384	0.24	0.812
M1 x L4	0.12	0.48	384	0.26	0.795
M2 x L4	0.47	0.47	384	1.01	0.314

Tab. A.18: Solutions for fixed effects used in the mixed procedure to test the significance of fertilisation and soil type on the distribution of AAC-P for the Warberg study site

Effect	**Solution for Fixed Effects**				
	Estimate	**Error**	**DF**	**t**	**p**
Intercept	292.31	58.77	383	4.97	<.0001
BB	6.50	33.61	383	0.19	0.847
GB	0.24	18.35	383	0.01	0.990
M1	-65.46	10.91	383	-6.00	<.0001
M2	-43.80	10.25	383	-4.27	<.0001
M3	0.00	-	-	-	-
L4	-20.98	41.50	383	-0.51	0.614
L5	-6.99	25.35	383	-0.28	0.783
LT4	-20.26	20.81	383	-0.97	0.331
LT5	-15.73	42.31	383	-0.37	0.710
T4	0.00	-	-	-	-
BB x L4	3.18	48.60	383	0.07	0.948
GB x L4	-16.97	37.75	383	-0.45	0.653
GB x L5	26.83	38.04	383	0.71	0.481
M1 x L4	15.23	35.09	383	0.43	0.664
M2 x L4	15.25	34.33	383	0.44	0.657

Tab. A.19: Solutions of the GLM procedure for fixed effects, parent material, land-use and soil type on the distribution of AR-P for the Ceveiro study site.

Effect	**Solution for Fixed Effects**				
	Estimate	**St. Error**	**DF**	**t-Value**	**p**
Intercept	1.15	0.332	241	3.46	0.001
Piramboia	-0.86	0.266	241	-3.22	0.002
Corumbatai	-0.43	0.260	241	-1.66	0.098
Serra Gerral	0.00	-	-	-	-
Sugar Cane	0.03	0.188	241	0.17	0.868
Pasture	0.09	0.237	241	0.37	0.710
Forest	0.00	-	-	-	-
Other soil types	-0.30	0.295	241	-1.03	0.306
Arenic Paleudult	-1.31	0.297	241	-4.43	<.0001
Typic Paleudalf	-0.19	0.346	241	-0.56	0.576
Typic Udorthent	0.00	-	-	-	-

Tab. A.20: Solutions of the GLM procedure for fixed effects, parent material, land-use and soil type on the distribution of WH-P for the Ceveiro study site.

	Solution for Fixed Effects				
Effect	**Estimate**	**St. Error**	**DF**	**t-Value**	**p**
Intercept	-0.30	0.32	245	-0.91	0.362
Piramboia	0.63	0.24	245	2.56	0.011
Corumbatai	0.38	0.24	245	1.56	0.121
Serra Gerral	0.00	-	-	-	-
Sugar Cane	0.19	0.23	245	0.82	0.414
Pasture	0.11	0.30	245	0.37	0.709
Forest	0.00	-	-	-	-
Other soil types	-0.42	0.24	245	-1.72	0.086
Arenic Paleudult	-0.47	0.24	245	-1.95	0.052
Typic Paleudalf	0.01	0.30	245	0.04	0.969
Typic Udorthent	0.00	-	-	-	-

Tab. A.21: Solutions of the GLM procedure for fixed effects, parent material, land-use and soil type on the distribution of AAC-P for the Ceveiro study site.

	Solution for Fixed Effects				
Effect	**Estimate**	**St. Error**	**DF**	**t-Value**	**p**
Intercept	-0.12	0.29	244	-0.40	0.691
Piramboia	0.65	0.24	244	2.65	0.009
Corumbatai	0.37	0.24	244	1.56	0.120
Serra Gerral	0.00	-	-	-	-
Sugar Cane	0.06	0.19	244	0.29	0.771
Pasture	0.12	0.26	244	0.48	0.630
Forest	0.00	-	-	-	-
Other soil types	-0.46	0.19	244	-2.47	0.014
Arenic Paleudult	-0.60	0.16	244	-3.79	0.000
Typic Paleudalf	0.07	0.23	244	0.30	0.765
Typic Udorthent	0.00	-	-	-	-

Tab. A.22: Solutions of the GLM procedure for fixed effects, parent material, land-use and soil type on the distribution of Resin-P for the Ceveiro study site.

	Solution for Fixed Effects				
Effect	**Estimate**	**St. Error**	**DF**	**t-Value**	**p**
Intercept	0.63	0.25	288	2.50	0.013
Piramboia	-0.21	0.21	288	-1.01	0.315
Corumbatai	-0.22	0.21	288	-1.08	0.280
Serra Gerral	0.00	-	-	-	-
Sugar Cane	0.05	0.17	288	0.30	0.764
Pasture	0.11	0.21	288	0.52	0.606
Forest	0.00	-	-	-	-
Other soil types	-0.37	0.17	288	-2.22	0.027
Arenic Paleudult	-0.97	0.15	288	-6.34	<.0001
Typic Paleudalf	0.09	0.21	288	0.45	0.656
Typic Udorthent	0.00	-	-	-	-

Tab. A.23: Solutions of the GLM procedure for the effects of covariates, on the distribution of AR-P for the Kassow study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Fertilisation	-1.56	0.32	186	4.86	<0.0001
Elevation	-2.54	1.30	186	1.95	0.052
Slope	0.00	-	-	-	-
Plan Curvature	0.00	-	-	-	-
Profile Curvature	0.00	-	-	-	-
LS Factor	-39.28	37.27	186	7.05	0.294
Wetness Index	0.00	-	-	-	-

Tab. A.24: Solutions of the GLM procedure for the effects of covariates, on the distribution of WH-P for the Kassow study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Fertilisation	-1.58	0.28	186	-5.69	<.0001
Elevation	-0.42	0.61	186	-0.7	0.485
Slope	0.00	-	-	-	-
Plan Curvature	0.00	-	-	-	-
Profile Curvature	0.00	-	-	-	-
LS Factor	0.00	-	-	-	-
Wetness Index	-5.37	2.96	186	-1.81	0.071

Tab. A.25: Solutions of the GLM procedure for the effects of covariates, on the distribution of AAC-P for the Kassow study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Fertilisation	-0.35	0.1304	186	-2.7	0.008
Elevation	0.00	-	-	-	-
Slope	0.00	-	-	-	-
Plan Curvature	0.00	-	-	-	-
Profile Curvature	0.00	-	-	-	-
LS Factor	0.00	-	-	-	-
Wetness Index	0.00	-	-	-	-

Tab. A.26: Solutions of the GLM procedure for the effects of covariates, on the distribution of $CaCl_2$-P for the Kassow study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Fertilisation	-0.03	0.01	184	-4.55	<.0001
Elevation	0.00	-	-	-	-
Slope	0.00	-	-	-	-
Plan Curvature	-1.62	1.09	184	-1.49	0.139
Profile Curvature	0.00	-	-	-	-
LS Factor	-3.81	0.84	184	-4.51	<.0001
Wetness Index	0.00	-	-	-	-

Tab. A.27: Solutions of the GLM procedure for the effects of covariates, on the distribution of AR-P for the Warberg study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	-1.24	0.87	383	-1.44	0.152
Slope	0.00	-	-	-	-
Plan Curvature	0.00	-	-	-	-
Profile Curvature	0.00	-	-	-	-
LS Factor	18.96	6.84	383	2.77	0.006
Wetness Index	0.00	-	-	-	-

Tab. A.28: Solutions of the GLM procedure for the effects of covariates, on the distribution of WH-P for the Warberg study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	-1.35	0.71	382	-1.89	0.060
Slope	135.41	102.45	382	1.32	0.187
Plan Curvature	266.17	102.51	382	2.60	0.010
Profile Curvature	0.00	-	-	-	-
LS Factor	20.44	6.33	382	3.23	0.001
Wetness Index	-3.22	4.50	382	-0.72	0.474

Tab. A.29: Solutions of the GLM procedure for the effects of covariates, on the distribution of AAC-P for the Warberg study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	-0.0045	0.037	383	-0.12	0.904
Slope	-19.72	3.54	383	-5.57	<0.0001
Plan Curvature	38.59	35.02	383	1.1	0.271
Profile Curvature	0.00	-	-	-	-
LS Factor	7.22	3.26	383	2.21	0.028
Wetness Index	-8.50	3.45	383	-2.47	0.014

Tab. A.30: Solutions of the GLM procedure for the effects of covariates, on the distribution of $CaCl_2$-P for the Warberg study site.

	Solution of Random Effects				
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	-0.01	0.00	384	-3.44	0.001
Slope	0.46	0.49	384	0.94	0.350
Plan Curvature	1.07	0.50	384	2.13	0.034
Profile Curvature	-0.27	0.05	384	-5.42	<.0001
LS Factor	0.14	0.05	384	3.01	0.003
Wetness Index	-0.12	0.05	384	-2.44	0.015

Tab. A.31: Solutions of the GLM procedure for the effects of covariates, on the distribution of AR-P for the Ceveiro study site.

		Solution of Random Effects			
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	0.23	0.05	241	4.47	<.0001
Plan Curvature	-0.05	0.04	241	-1.34	0.183
Profile Curvature	-0.02	0.03	241	-0.76	0.450
Slope	0.00	.	.	.	.
LS Factor	-0.08	0.04	241	-1.80	0.074
Wetness Index	0				
Sugar Cane x others	-0.093	0.144	241	-0.64	0.520
Sugar Cane x Arenic Paleudult	0.057	0.146	241	0.39	0.695
Sugar Cane x Typic Paleudalf	0.029	0.153	241	0.19	0.851
Sugar Cane x Typic Udorthent	0.006	0.141	241	0.05	0.963
Pasture x others	-0.038	0.149	241	-0.25	0.800
Pasture x Arenic Paleudult	-0.001	0.158	241	-0.01	0.993
Pasture x Typic Paleudalf	-0.031	0.156	241	-0.20	0.841
Pasture x Typic Udorthent	0.071	0.148	241	0.48	0.635
Forest x others	0.131	0.148	241	0.88	0.380
Forest x Arenic Paleudult	-0.056	0.147	241	-0.38	0.705
Forest x Typic Paleudalf	0.002	0.158	241	0.01	0.988
Forest x Typic Udorthent	-0.077	0.146	241	-0.53	0.599
Piramboia x others	-0.073	0.186	241	-0.39	0.695
Piramboia x Arenic Paleudult	0.015	0.182	241	0.08	0.934
Piramboia x Typic Paleudalf	0.189	0.204	241	0.93	0.355
Piramboia x Typic Udorthent	-0.131	0.195	241	-0.67	0.503
Corumbata x others	0.032	0.185	241	0.17	0.865
Corumbatai x Arenic Paleudult	-0.088	0.181	241	-0.49	0.625
Corumbatai x Typic Paleudalf	-0.088	0.199	241	-0.44	0.660
Corumbata x Typic Udorthent	0.145	0.191	241	0.75	0.451
Serra Geral x Others	0.041	0.199	241	0.21	0.835
Serra Geral x Arenic Paleudult	0.073	0.194	241	0.38	0.706
Serra Geral x Typic Paleudalf	-0.101	0.209	241	-0.48	0.630
Serra Geral x Typic Udorthent	-0.014	0.209	241	-0.06	0.948

Tab. A.32: Solutions of the GLM procedure for the effects of covariates, on the distribution of WH-P for the Ceveiro study site.

		Solution of Random Effects			
Covariates	Estimate	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	0.17	0.07	245	2.59	0.010
Plan Curvature	.	.	.		
Profile Curvature	.	.	.		
Slope	0.00	.	.	.	.
LS Factor	-0.08	0.06	245	-1.48	0.141
Wetness Index	0.10	0.06	245	1.78	0.077
Sugar Cane x others	-0.09	0.16	245	-0.57	0.567
Sugar Cane x Arenic Paleudult	0.05	0.16	245	0.30	0.766
Sugar Cane x Typic Paleudalf	0.01	0.17	245	0.07	0.946
Sugar Cane x Typic Udorthent	0.03	0.16	245	0.21	0.838
Pasture x others	-0.02	0.16	245	-0.11	0.911
Pasture x Arenic Paleudult	-0.02	0.17	245	-0.15	0.885
Pasture x Typic Paleudalf	-0.02	0.17	245	-0.14	0.892
Pasture x Typic Udorthent	0.07	0.16	245	0.41	0.685
Forest x others	0.11	0.16	245	0.67	0.503
Forest x Arenic Paleudult	-0.02	0.16	245	-0.14	0.887
Forest x Typic Paleudalf	0.01	0.17	245	0.07	0.946
Forest x Typic Udorthent	-0.10	0.16	245	-0.61	0.541

Tab. A.33: Solutions of the GLM procedure for the effects of covariates, on the distribution of AAC-P for the Ceveiro study site.

		Solution of Random Effects			
Effect	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	0.15	0.07	244	2.21	0.028
Plan Curvature	0	.	.	.	.
Profile Curvature	0	.	.	.	.
Slope	0	.	.	.	.
LS Factor	-0.14	0.06	244	-2.29	0.023
Wetness Index	0.09	0.05	244	1.64	0.102

Tab. A.34: Solutions of the GLM procedure for the effects of covariates, on the distribution of Resin-P for the Ceveiro study site.

		Solution of Random Effects			
Covariates	**Estimate**	**Std. Err Pred**	**DF**	**t-Value**	**p**
Elevation	0.162	0.056	288	2.88	0.004
Plan Curvature	-0.029	0.037	288	-0.79	0.431
Profile Curvature	-0.027	0.034	288	-0.80	0.424
Slope	0.000	.	.	.	.
LS Factor	-0.121	0.053	288	-2.28	0.023
Wetness Index	0.069	0.047	288	1.47	0.143
Sugar Cane x others	-0.036	0.073	288	-0.50	0.621
Sugar Cane x Arenic Paleudult	0.020	0.073	288	0.28	0.780
Sugar Cane x Typic Paleudalf	0.000	0.075	288	0.00	0.999
Sugar Cane x Typic Udorthent	0.016	0.073	288	0.22	0.826
Pasture x others	0.016	0.074	288	0.22	0.827
Pasture x Arenic Paleudult	-0.013	0.075	288	-0.17	0.867
Pasture x Typic Paleudalf	-0.002	0.075	288	-0.03	0.979
Pasture x Typic Udorthent	-0.002	0.074	288	-0.02	0.983
Forest x others	0.020	0.074	288	0.27	0.787
Forest x Arenic Paleudult	-0.008	0.074	288	-0.11	0.915
Forest x Typic Paleudalf	0.002	0.075	288	0.03	0.978
Forest x Typic Udorthent	-0.014	0.074	288	-0.20	0.845

Tab. A.35: Significance of effect of the soil texture on the distribution of P fractions for the Kassow study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
P fraction	**Num DF**	**Den DF**	**F-Value**	**p**
AR-P	3	186	2.01	0.114
WH-P		186	3.42	0.0184
AAC-P	3	186	1.01	0.390
$CaCl_2$-P	3	184	5.10	0.002

Tab. A.36: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of AR-P for the Warberg study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
Fields	4	383	1.95	0.101
Soil	4	383	2.37	0.052
Fields x Soils	5	383	1.97	0.083

Tab. A.37: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of WH-P for the Warberg study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
Fields	4	383	2.59	0.037
Soil	4	383	1.40	0.234
Fields x Soils	5	383	0.49	0.782

Tab. A.38: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of AAC-P for the Warberg study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
Fields	4	383	7.40	<0.0001
Soil	4	383	1.04	0.386
Fields x Soils	5	383	1.40	0.222

Tab. A.39:Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of $CaCl_2$-P for the Warberg study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
Fields	4	383	13.09	<0.0001
Soil	4	383	1.25	0.289
Fields x Soils	5	383	0.41	0.84

Tab. A.40: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of AR-P for the Ceveiro study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
GEO	2	241	5.44	0.005
USE	2	241	0.07	0.932
SOIL	3	241	7.96	<.0001

Tab. A.41: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of WH-P for the Ceveiro study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
GEO	2	245	3.58	0.030
USE	2	245	0.34	0.712
SOIL	3	245	1.92	0.128

Tab. A.42: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of AAC-P for the Ceveiro study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
GEO	2	244	3.91	0.021
USE	2	244	0.12	0.890
SOIL	3	244	6.29	0.000

Tab. A.43: Significance of effect of the fixed factors, parent material, land-use and soil type, on the distribution of Resin-P for the Ceveiro study site. The significance of each partial effect was examined, that is, the significance of an effect with all the other effects in the model (Type III).

		Type 3 Tests of Fixed Effects		
Effect	**Num DF**	**Den DF**	**F-Value**	**p**
GEO	2	288	0.61	0.543
USE	2	288	0.13	0.875
SOIL	3	288	16.91	<.0001

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