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SPATIAL ANALYSIS OF CROP SYSTEMS IN RELATION TO PEDOCLIMATIC CONDITIONS IN EUROPE AND CHINA

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Executive summary

Our analysis highlights the main features of farming by soil in Europe and China. Farming by soil in this context mean the consideration of the soil type and soil properties when selecting crop types and cropping patterns. Our analysis focused on land-based agriculture, i.e. large scale open-air arable farming.

We studied the cropping patterns in climate zones with regards to the shares of crop types in different soils. Similarities and differences of the distribution of crop types on different soils within climatic zones was assessed in a comparative manner. We first assessed the dissimilarity between the cropping compositions of different pedoclimatic zones. Next, we assessed the differences of crop distribution in the climate zone by soil types and main crop types, by analysing the degree of association of crops to soil types.

Results suggest, that farmers in general are consciously take pedoclimatic condition of farming into account when selecting their cropping patterns in Europe. In other words, farming by soil is a common practice in the different (climatic) regions of Europe. Pedoclimatic conditions are considered in their complexity by the farmers. For instance oil crops are cultivated on relatively high share of Podzols in Mediterranean (temperate-sub oceanic) and low share of Podzols in southern sub-continental zone, meaning that similar specific soil conditions are considered together with the prevailing climatic conditions. Other good examples of soil-based farming include root crop production on Histosols in the Atlantic climate zone, maize production on Gleysosls of the Southern sub-continental climate, cultivating cereals on Podzols of the Sub-Oceanic climate zone, which all can be regarded as a “farming by soil” practice, which is also recognized on this coarse scale of analysis.

The fact that both zonal and azonal soils are among the soil types that might be cropped differently from the main cropping pattern of the given regions show that apart from climatic factors soil conditions have dominant role in selecting the most suitable crop.

However, we have strong reasons to believe that soil suitability-based cropping is not practiced to its full potential over the continent at the moment. For example our finding suggests that production area of legumes are not always adapted till their full potentials for the local pedoclimatic conditions in some zones. We assume that the reason for this the consideration of legumes mostly “only” as an internal crop filling the cultivation gap between the preferred cash crops, rather than placing legumes in the rotation on their own right for balanced soil utilization. Probably including legumes to the rotations based on pedoclimatic conditions would enhance the overall agronomical output as well. However, cropping desirable from agronomic viewpoint is not necessarily meet the profitability targets of the farm enterprises.

When comparing our findings with time series statistical data of crop cultivation (Eurostat 2017) we can assume that tendencies driven by policy incentives or climate change can restructure the crop composition of pedoclimatic zones rather rapidly too. Findings of farming in pedoclimatic zones under the Atlantic climate underlines that economic drivers are decisive when farmers adopt their cropping (eg. oil crops on Albeluvsiols), however soil suitability is considered too and may result in win-win situations for the economic return of crop production and management based on soil suitability (roorcrops on Histosols; cereals on Arenosols).

In conclusion, we can assume that pedoclimatic conditions of cropping are respected in most of Europe. Farmers crop according to edaphic conditions whenever economic considerations do not override the ecological consideration of farming.

Obviously, the farming activity in China is generally conducted on reasonable soil types according to the long agricultural history. Our results revealed the difference of main soil types in each pedoclimatic zone regarding crop types. For various climatic zones, agricultural use of soil would give rise to different problems that should be paid extra attentions to. For example, in the tropical climate area, Ferralsols could be improved by highly technical interventions and the intensive use may lead to compaction problems due to their aggregate and pore morphology. Furthermore, Ferralsols soils are very friable and are easy to manage and present a low CEC and quick drainage. Cultivation on the Acrisols would exposes soils to significant erosion, in that Tropical climate zone usually has a large annual precipitation.

Generally speaking, the cropping patterns of all the soil types are not significantly different with each other according to the Chi square statistics. There are two potential reasons for the insignificant difference: 1) some soil types with small areal shares present dominant difference versus other soil types; and 2) the ownership of most croplands in China was very scattered (only a few tenths of hectares) due to the large population and little farmland, and this heterogeneity increases the uncertainties of the input data applied in the analysis.

1. Introduction

Land users need to optimize their cropping patterns, cropping systems and their farming systems as a whole for the prevailing ecological conditions. Most scientists and farmers are involved in the promotion of sustainable agriculture for the creation of an agriculture that maintains productivity in the long term, by optimizing the use of locally available resources, including climatic and edaphic resources, relying on nutrient recycling, reducing the use of external and non-renewable input. Improving the synergies between soil quality and cropping patterns can secure long-term sustainability of production.

In many countries and in recent years there is a tendency towards cereal grain stagnation and increased yield variability. Some of these trends may have been influenced by the recent climatic changes over Europe. For many environmental zones, there were clear signs to face more deteriorating agro climatic condition in terms of increased drought stress and shortening of the active growing season, which, in some regions become increasingly squeezed between a cold winter and a hot summer.

Climatic changes in general are likely to shift the zonation of optimal production areas for specific crops within the EU. Temperature increases tend to speed the maturation of annual crops, therefore reducing their total yield potential. The combination of zonal shift and productivity changes may affect the total agricultural output of the EU and its share of international commodity trade.

The most negative effect of climate change is projected for agriculture of the region in continental climate. In Europe it covers the Pannonian zone, which includes Hungary, Serbia, Bulgaria and Romania. This region is projected to suffer from increased incidents of heat waves and drought, without possibilities for effectively shifting crop cultivation to other parts of the years. Although there is little opportunity to adaptation of rainfed production in this zone, there may be some scope for the introduction of new crops (AEA2007, Németh, L. 2008). For most other climate zones the projections show a marked need for adaptive measures to either increase soil water availability or drought resistance of crops. Rainfed agriculture is likely to face more climate-related risks, although the analysed agroclimatic conditions will probably remain at a level that should permit rainfed production. (Olesen, 2011, Trnka M.2011). However, the conditions of rainfed productions will be in the suboptimal trend.

Consequently, strategies need to be developed to adopt cultivars or crops better suited to water and heat stress. Problems from new pest and diseases are also considered a high risk as climate changes. Higher diversity of a crops leads to less risk from the viewpoint of climatic stress and less financial risk too.

Consideration of ecological conditions, including soils is key to the success and sustainability of farming. However, so far little scientific research has been made to assess the relationship between soil quality and composition of crops. (In Europe, China and globally.)

Our analysis aimed to fill this information gap and targeted to reveal the relationship between cropping practices and soil conditions in Europe (and China). In this analysis we considered the experiences from previse projects (ECOFinders, RECARE, MyWater, CATCH-C, D-e-METER), which dealt with soil productivity, crop requirements, water availability and climatic suitability. Soil quality, including water management and nutrient availability is an essential property of soil types, therefore we performed our analysis based on soil types. To enable integrated analysis of complexity in the climate-soil-crop system, cropping pattern by soil types were assessed in the main climate zones. Our analysis focused on land-based agriculture, i.e. large scale open-air arable farming.

This report details the data used, methods applied and the results of the assessment which was performed to analyse arable cropping systems in the pedoclimatic zones of Europe.

2. Materials and methods

2.1 Identification of cropping system in pedoclimatic zones using spatial datasets

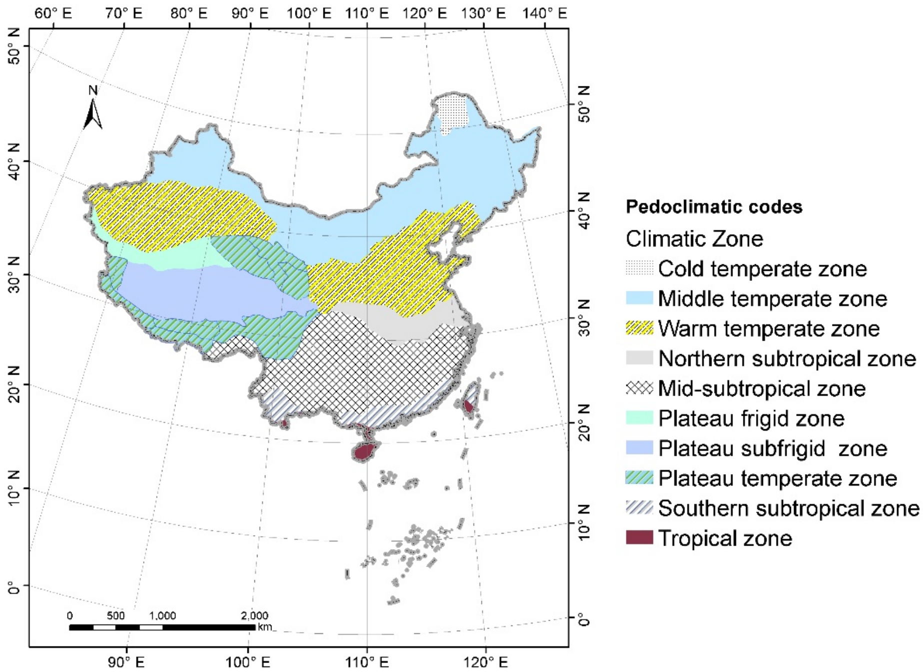
2.1.1 Europe

Pedoclimatic zones were delineated by overlapping the layer of European climatic zones geodatabase – as reclassified for soil productivity evaluation by Tóth et al. (2013) based on the zonation of Hartwich et al. (2005) – with the layers of soil types (Reference Soil Groups, RSGs, WRB1998) of the European Soil Database (ESDB, EC 2003). Physical area for crops was calculated for each pedoclimatic zone using the MapSpam 2005 dataset developed by You et al. (2014).

2.1.2 China

The climate zone map of China (Figure 1, 1:8,000,000) was provided by the China Meteorological Administration (CMA, 2011). Generally speaking, this partition is similar to the Chinese geomorphological zones (Figure 1).

Figure 1. Climate zones in China



The update of current HWSD involves mainly the use of the new version of WRB soil classification system and supplementing existing polygons with new pedon data as available. The level of update is cross-border integration of national updates over the entire China. The maps and databases were merged by ISSCAS.

2.1.3. The cropping systems of the study

As a result of the spatial data processing (2.1.1, 2.1.2) we created geodata layers containing the information of the physical area covered by each crop in each pedoclimatic zones. We focused on the following cropping system classes: cereals (barley, millet pearl, millet small, sorghum, wheat and other cereals), maize, legumes (bean, chickpea, cowpea, lentil, pigeon pea, and other pulses), oil crops (groundnut, oil palm, rapeseed, sesame, soybean, sunflower and other crops), root crops (cassava, potato, sweet potato, yam, and other roots and tubers), sugar crops (sugar beet and sugar cane), and vegetables. Spatial analysis was performed in ArcGIS 10.4.

2.2 Statistical analysis to reveal spatial characteristics of crop systems in relation to pedoclimatic conditions

Similarities and differences of the distribution of crop types on different soils within climatic zones was assessed in a comparative manner using dissimilarity analysis.

We first assessed the dissimilarity between the cropping compositions of different pedoclimatic zones.

Dissimilarity was calculated with 'vegan' package (Oksanen et al., 2017). We computed Bray–Curtis dissimilarity index with vegan R package to quantify dissimilarity of RSGs based on the distribution of their cropping systems in pairwise comparisons. The dissimilarity index reaches its maximum value one when there are no shared cropping system classes between two compared RSGs. Analysis has been performed for each climatic zones separately. Function decostand was used to standardize the values.

The matrix of dissimilarity index shows the differences between the compositions of cropping systems of the compared PCZs (soil types) by climate zone. Darker the cell in the matrix, larger the difference between the cropping compositions of the two compared PCZs (soil types) within the given climate zone. Clustering of dissimilarity indices was performed using the Euclidian distances of cropping patterns derived from normalised area of the crops within the climate zone. Dendrograms display the clusters of soils based on the similarity of their cropping patterns. Dendrorams are displayed next to the dissimilarity matrix.

Next, we assessed the differences of crop distribution in the climate zone by soil types and main crop types, by analysing the degree of association of crops to soil types.

Association was analysed with 'vcd' R package (Meyer at al., 2016). Association plot (Meyer et al., 2003): „reject the null hypothesis of independence of the two categorical variables when there are residuals which are too extreme, i.e., not close enough to zero. This is the well-known χ^2 test for independence in 2-way tables. When the χ^2 test statistic turns out to be significant for some data, it seems natural to go back to its components, i.e., the residuals, for a more detailed analysis. Association plots visualize the table of Pearson residuals (Zeileis et al., 2007, Meyer et al., 2006): each cell is represented by a rectangle that has (signed) height proportional to the corresponding Pearson residual and width proportional to the square root of the expected counts. The highlighted cells are those with residuals individually significant at approximately the 5% and 0.01% level. The main purpose of the shading is not to visualize significance but the pattern of deviation from independence."

On the conditional association plot the horizontal size of the bars are (i) relative to the square root of the areas of soil types (PCZs) used for the observed crop within the CZ i.e. for comparison between soil types (same in each column) and (ii) relative to the square root area of the given crop type on the agricultural area of the CZ, i.e. for comparison between the crop types (same in each row).

Vertical extent of the bars show the deviation of the given crop's areal share on the observed soil from the average of those in the total agricultural land of the CZ.

Thus, the graph shows the reason for the difference too: crops occupying significantly higher or lower share within the given PCZ (soil type) than their average share within the climate zone turns higher up or deeper down from the zero line, respectively, depending on the level of significance of this difference. The height or depth of the bar, also highlighted by its colour indicates the level of significance in this difference.

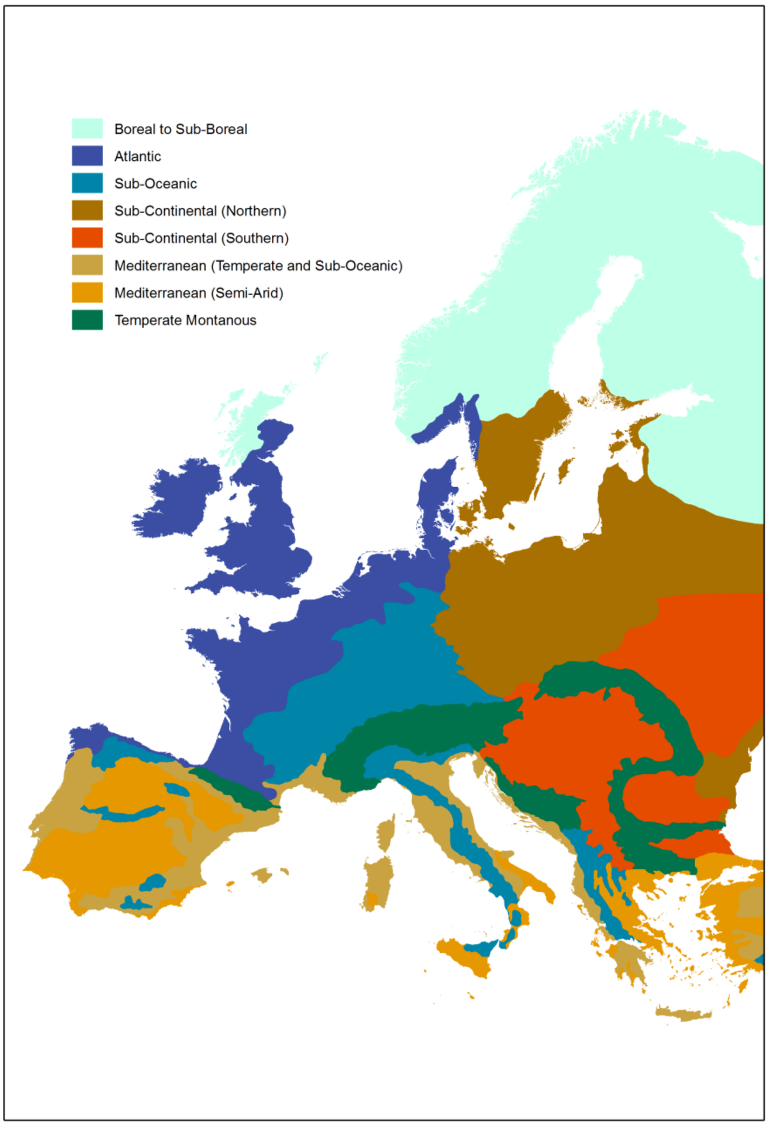
We analysed with Chi-squared test (Everitt and Hothorn, 2010) if RSGs are significantly different regarding the distribution of the farming systems. Test has been performed on each RSG pairs.

Those soil types are considered, which occupy at least 1% of the area of the climate zone and of which at least 10% is cultivated.

3. Crop systems in relation to pedoclimatic conditions in Europe

The analysis of crop systems in the pedoclimatic zones was performed by main climate zones. Map of figure 2. shows the main climate zones in Europe.

Figure 2. Climate zones in Europe



3.1. Comparative assessment of crop systems on different soils of the Atlantic climate zone

According to the statistical comparison displayed also in the evaluation matrix (Fig. 2a), cropping pattern of Histosols differs from those on most other soil types except for Fluvisols and Podzols to the greatest extent. Furthermore the cropping pattern of Albeluvisols is significantly different from those of Arensools, while the cropping pattern of Arenosols is also significantly different from that of Fluvisols (besides Albeluvisols and Histosols).

The difference in the pattern of Histosol cultivation is largely due to the relatively high share of rootcrops on this soil type, which is cultivated on a significantly higher share of the area of this soil than on other soil types in the Atlantic climate zone (Fig. 2b). Histolsols are soils of loose structure, which is optimal for growing root crops. Therefore favouring root crops on this soil can be considered as good agronomic practice. According to our findings rootcrops are given preference over maize, and to some extent oil crops on these soils. Potato and sugar beet are predominant among rootcrops of the climate zone. Both crops are selective in their forecrops and may return to the rotation after 4 years. The high spatial extent of rootcrops on Histosols suggest that farmers aim the maximum capacity of rootrcrop (potato and sugar beet) production on these soils, considering agronomic possibilities.

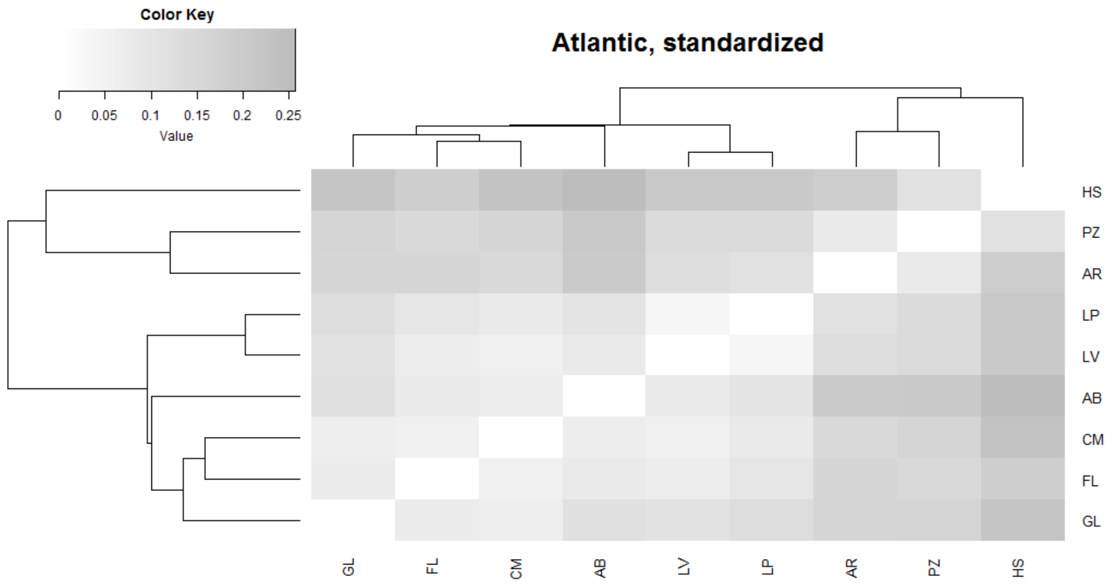


Figure 2a. Dissimilarity indices matrix of cropping systems by RSGs in the Atlantic climatic zone

On Albeluvisols areas proportionally more oilcorps (rapeceed) and maize are grown than on Arenoslos and Histosols. In the meantime the proportional areas of rootcrops and cereals are smaller. As Albeluvisols are generally low fertility soils not particularly suitable for arable cropping, the relatively higher share of cashcrops may be a result of intensive cultivation driven by economic incentives, rather than a search for the most suitable crops.

Dominancy of cereals on Arenosols can be explained by the advanced technologies of high intensity farming for these crops. Moisture availably, which is often the limiting factor for cereal cultivation is secured under the Atlantic climate. Easy workability and weed control along with well-planned nutrient management can secure high returns from cereals in this pedoclimatic zone.

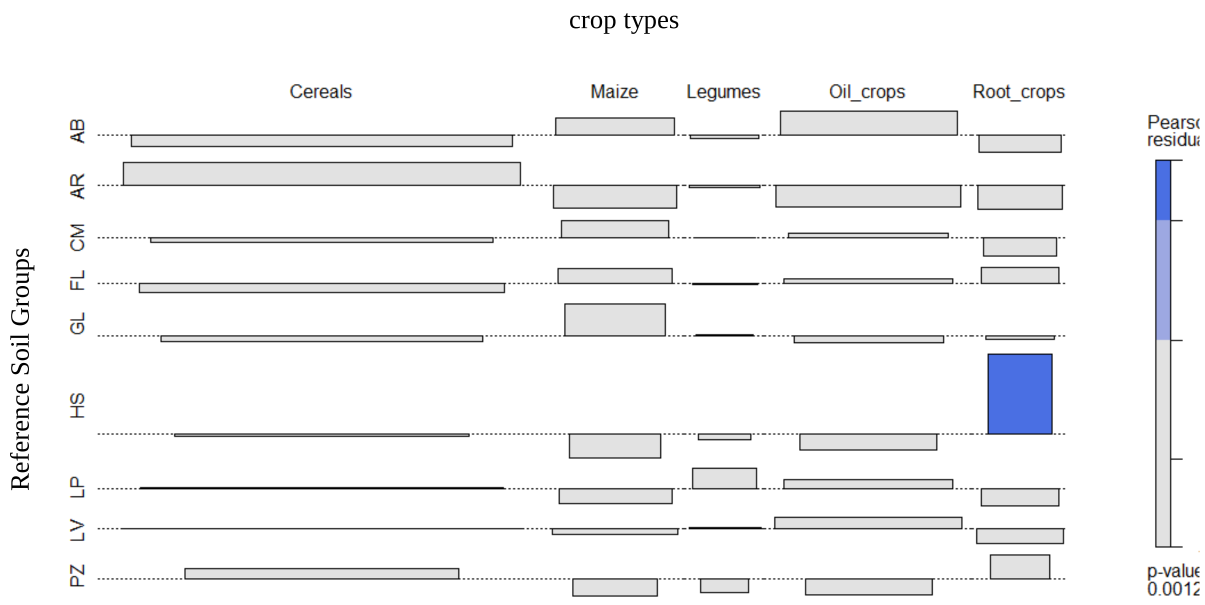


Figure 2b. Conditional association plots of cropping systems by RSGs in the Atlantic climatic zone

Results of the Chi square statistics:

- *HS is significantly different from AB, AR, CM, GL, LP, LV (and almost from FL, but not from PZ),*
- *AB is significantly different from AR, HS (and almost from PZ),*
- *AR is significantly different from AB, FL, HS (and almost from GL),*
- *FL is significantly different AR (and almost from HS),*
- *GL is significantly different from HS (and almost from AR),*

at 0.05 level.

3.2. Comparative assessment of crop systems on different soils of the Sub-Oceanic climate zone

Cropping on Podzols and Gleysols is somewhat different from those on the rest of the soil types (Figs. 3a, 3b). A higher share of cereals and lower share of oil crops is observed in the cultivation pattern of these two soils in the Sub-Oceanic climate zone. However, these differences are not significantlyificant. Nevertheless, cultivation of cereals on Podzols is successful if moisture is available and fertilization is adequate. Both conditions are given in this climate zone and its countries with agriculture of advanced technological levels. Rapeseed, which is the predominant oilcrop in the region and which is primarily cultivated for animal feed and also for canola oil, has a need for quality seedbed preparation and high input of nutrients. The easy workability of Podzols would make them optimal for rapeseed production. However, disparity between the high nutrient demand of rapeseed and the low nutrient supply of Podzols can be lessened probably only with such high inputs, which are not economic. Cambisols and to some extent Luvisols, Leptosols and Regosols of the region are more suitable for rapessed than for more demanding crops like maize, which is reflected in the cultivation share of those soils.

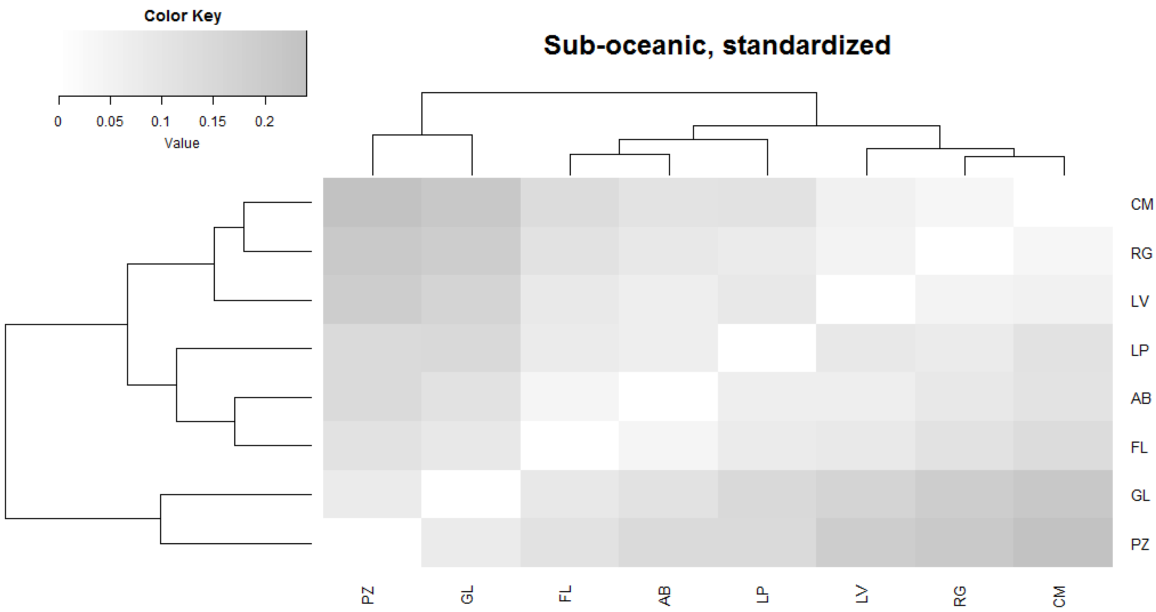


Figure 3a. Dissimilarity indices matrix of cropping systems by RSGs in the Sub-Oceanic climate zone

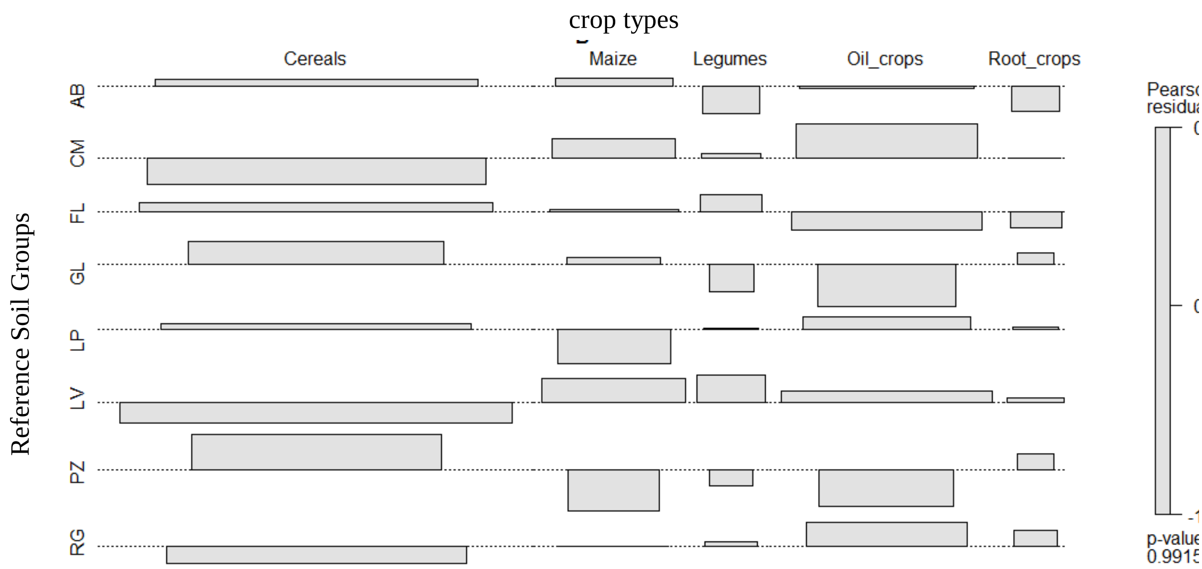


Figure 3b. Conditional association plots of cropping systems by RSGs in the Sub-oceanic climate zone

Cereals and oil crops have similar share on Gleysols to those on Podzols. However, Gleysols have higher share of maize. Gleysols are hydromorpic soils, of which the subsoil is wet for most part of the year, therefore cultivating maize – a crop of high water and nutrient demand – can be regarded an appropriate practice from pedological viewpoint on areas with light to medium or medium-heavy texture.

It is worth emphasising once again that while cultivation patterns of different soil types show slight variations, these variations do not reach the degree to be significant.

Chi square statistics: There is no significantly difference between any RSG at 0.05 level.

3.3. Comparative assessment of crop systems on different soils of the Northern Sub-Continental climate zone

Kastanozems have significantly different cropping pattern from all other soil types, which are cropped similarly to each other (Figs. 4a, 4b). High share of maize and oil crops on Kastanozems present the difference from cropping on other soils. Kastananezoms considered to be the best soils in the region, with good structure, favourable water retention and conductivity characteristics and rich nutrient reserves. Furthermore these soils situate on the southern parts of the climate zone making it favourable for crops with higher temperature needs. The areal share of maize cultivation on Kastanozems is so high, that it alone shifts the average value of corn for the entire region. As a result, the share of maize on all other soil types differs significantly. Oilcrops have relatively high share on Kastanozems too. From the viewpoint of climatic suitability, rapeseed is the main oilcrop to grow in this zone. Rapeseed, along with maize, is among the most demanding crops regarding nutrient uptake, especially P, of which high stock is available in Kastanozems. Cereals and rootcrops, on the other hand can be cultivated successfully on other soils too. Although Kasetnozems would be their most suitable growing medium, higher economic return of oilcrops and maize supress cereal and rootcrop areas in this zone.

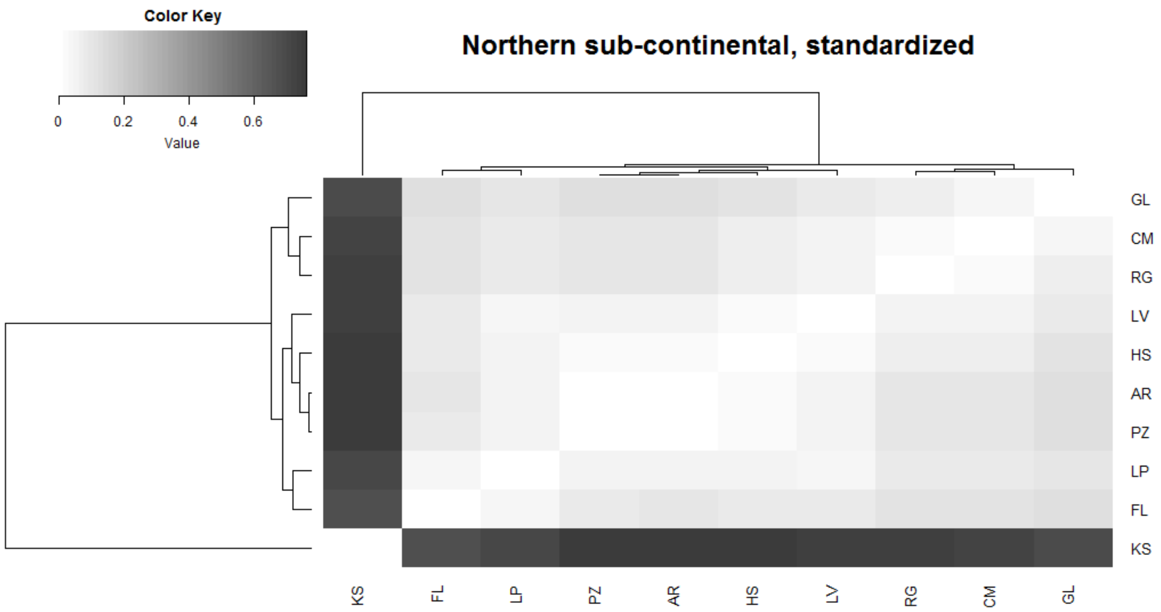


Figure 4a. Dissimilarity indices matrix of cropping systems by RSGs in the Northern sub-continental climate zone

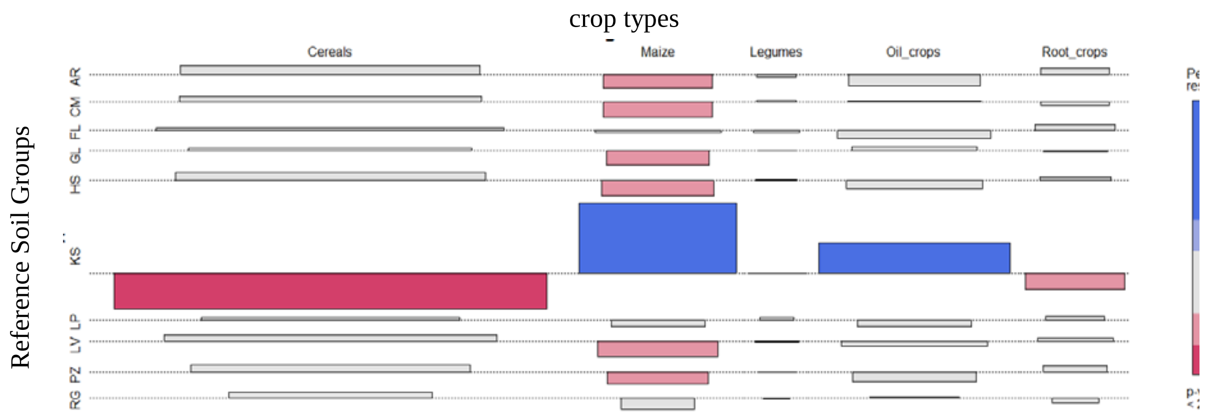


Figure 4b. Conditional association plots of cropping systems by RSGs in the Northern Sub-Continental climate zone

Results of the Chi square statistics:

- *KS is significantly different from all other RSG at 0.05 level.*
- *Other RSG are not significantly different from each other.*

3.4. Comparative assessment of crop systems on different soils of the Mediterranean Semi-Arid climate zone

Great variability of crop distribution by soil types is found in the Mediterranean Semi-Arid zone (Figs. 5a, 5b). Especially Acrisols, Calcisols, and Fluvisols show divergence from other soil types in their cropping patterns. Acrisols, soils with rather poor fertility and low pH are not preferred for cereal cultivation but have significantly higher share of oil crops than any other soil types. Sunflower is the predominant oilcrop in this climate zone. Sunflower is tolerant to lower pH, which makes Acrisols acceptable edaphic environment for sunflower especially in contrast to maize, but also to cereals in general, which prefer soils with rather neutral reaction. Calcisols, on the contrary, have a significantly lower share of oil crop (sunflower) and significantly higher share of cereals than the average share of Acrisols, Vertisols and Regoslos. The cropping pattern of Fluvisols is significantly different from that of Acrisols and Vertisols too and these differences are caused by the low share of oil crops on Fluvisols. Both Calcisols and Fluvosols have higher shares of cereals, which is significantly higher on Calcisols, than those of all other soil types. Both Fluvisols and Calcisols are among the fertile soils of the region, although the fertility of Calcisols may be limited by the availability of trace elements, especially Fe and Zn. Nevertheless our analysis shows that the distribution of crops follow the pedoclimatic conditions in this climatic zone.

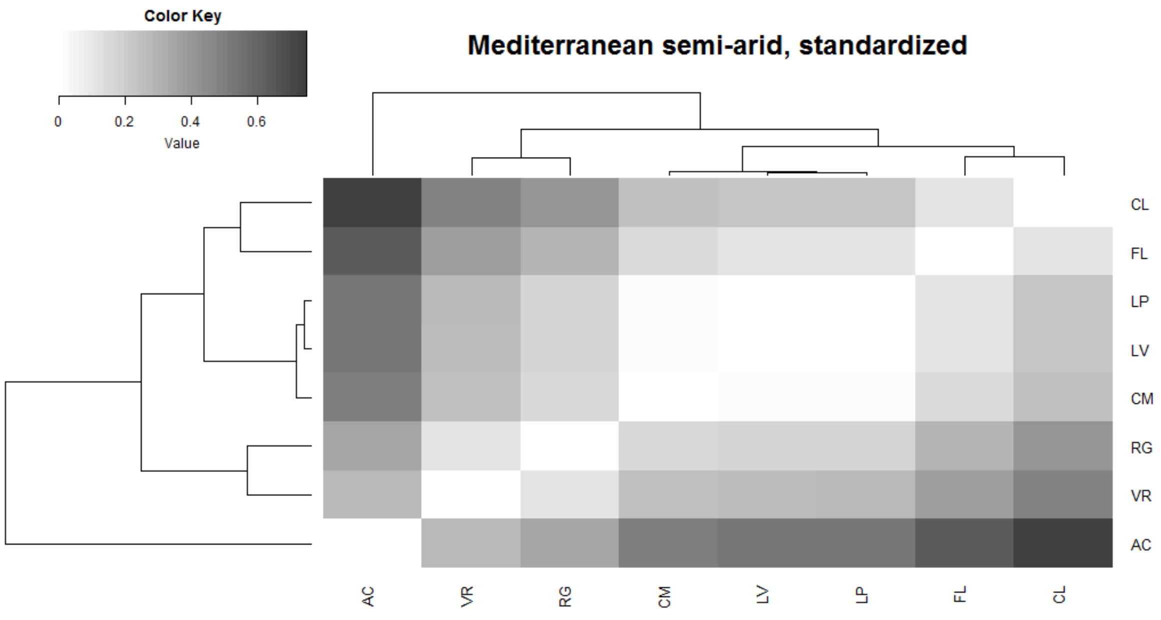


Figure 5a. Dissimilarity indices matrix of cropping systems by RSGs in the Mediterranean, semi-arid climate zone

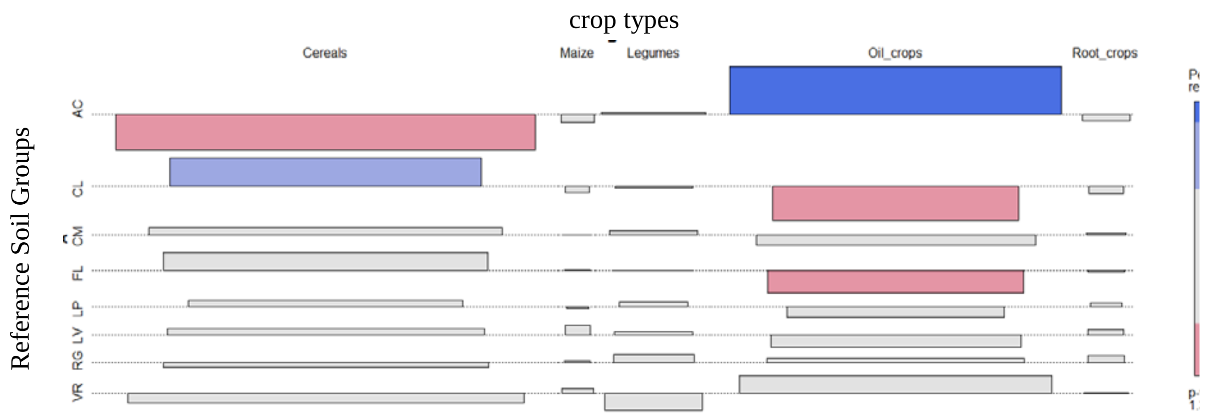


Figure 5b. Conditional association plots of cropping systems by RSGs in the Mediterranean semi-arid climate zone

Results of the Chi square statistics:

- *AC is significantly different from all other RSG,*
- *CL is significantly different from AC, RG, VR,*
- *FL is significantly different from AC, VR,*

at 0.05 level.

3.5. Comparative assessment of crop systems on different soils of the Southern subcontinental climate zone

There are two types of soils of which the cropping pattern deviates from the typical pattern of the zone, namely Gleysols and Podzols (Figs. 6a, 6b). Distribution of crops on Gleysoils significantly differs from that on Podzolz, Histosols and Leptosols and the share of its maize growing area is significantly higher than that of any other soil type of the zone. This is explained by the hydromorphic features and consequent water regime of Gleysols. Cultivating maize on Gleysols can be successful under this climate, because water supply on Gleysols can be secured from groundwater also during the critical periods in July and August, when climatic drought is frequent and water demand of maize is the highest. Favouring maize to cereals on Gleysols have another pedoclimatic reason too. Gleysols are among the soils which are most prone to excess water, especially in early spring, which presents high risk in the cultivation. This risk can be lessened if spring crops with sowing time after the wettest period are cultivated. Majority of cereals are autumn plants under this climate, thus maize is an excellent alternative for that reason too. As the sowing time of maize is normally after the period of highest inland water risk, cultivating maize on Gleysosls can be regarded as a win-win situation.

Podzols are situated in those parts of the Southern subcontinental climate zone, which has relatively higher precipitation and consequent lower mean temperature. Probably this is one of the reasons for their unique cropping pattern including high shares of cereals, which is different from those of all other soil types in the climate zone, rather than their pedological properties. Apart from the relatively high rate of cereals, root crops (predominantly potato) which are also abundant in this zone have wide climatic suitability as well. However, in the case of rootcrops edaphic suitability plays an equally important role too, as the loose topsoil structure of Podzols is favourable for rootcrop.

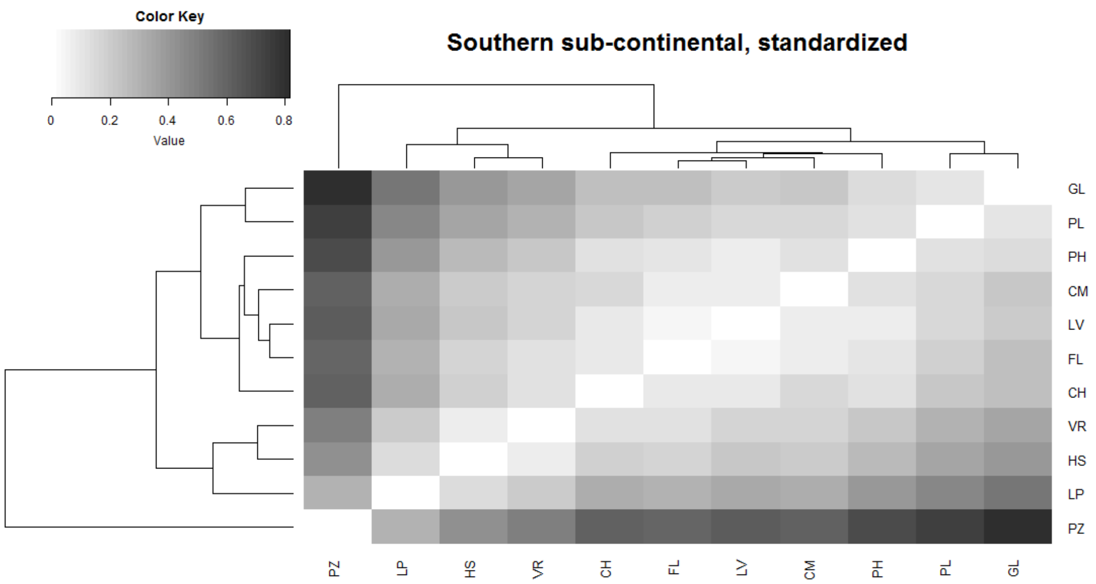


Figure 6a. Dissimilarity indices matrix of cropping systems by RSGs in the Southern Sub-Continental climate zone

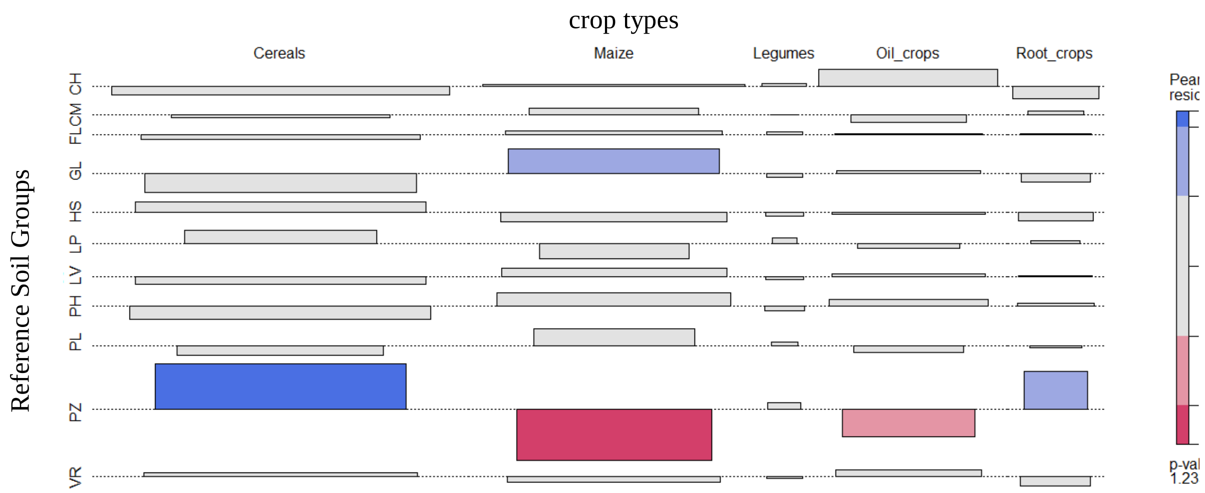


Figure 6b. Conditional association plots of cropping systems by RSGs in the Southern Sub-Continental climate zone

Results of the Chi square statistics:

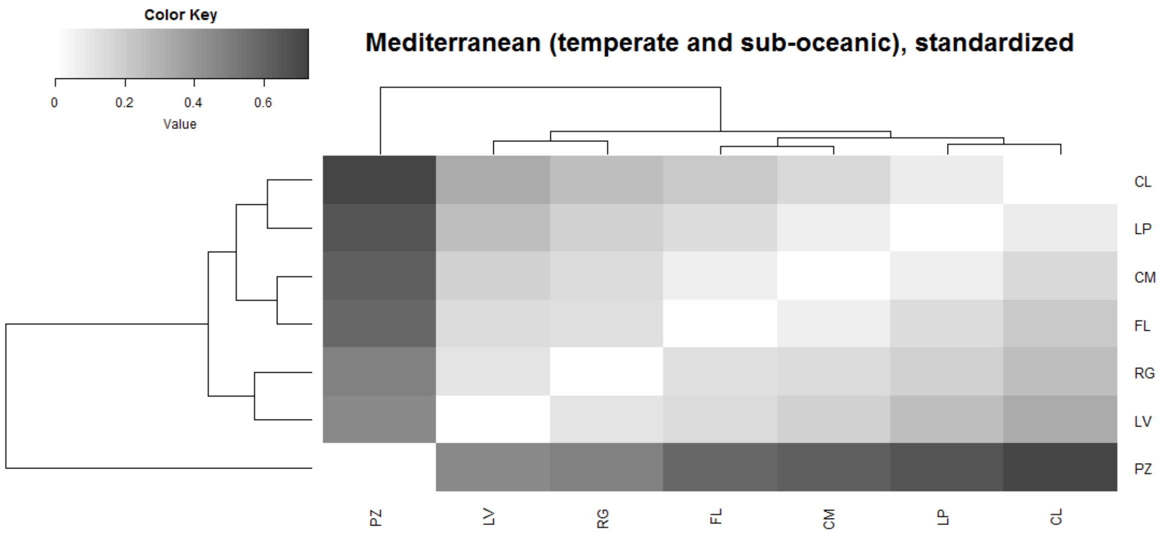
- *Podzols are significantly different from all other RSG,*
- *Gleysols are significantly different from HS, LP, and PZ,*

at a 0.05 level.

3.6. Comparative assessment of crop systems on different soils of the Mediterranean (temperate and sub-oceanic) climate zone

Calcisols and Podzols are the two soil types of which the cropping pattern differs from those of most other soils in the Mediterranean (temperate and sub-oceanic) climate zone (Figs. 7a, 7b). In fact, these are the two soils with the largest (Calcisols) and smallest (Podzols) area cover of agricultural land in this climate zone. Podzols are cultivated for oil crops in significantly higher share than any other soil type under this climate, and the areal share of root crops is also rather high on Podzols. Legumes, maize and cereals, on the other hand occupy relatively smaller areas, although not significantly smaller, than on other soils in the zone. We believe that this cultivation pattern is reflecting the suitability of Podzols for crops which require loose soil structure and have tolerance to moderately acidic pH. Calcisols, being one of the most fertile soils in the zone is mainly cultivated for cereals and oilcrops, which are also the two most abundant crop groups of the zone. Although the relative share of cereals is higher and oil crops is lower than the average of the zone, these differences are not significant. The same applies for the relatively larger areas of legumes. Maize, on the other hand is cultivated on significantly smaller shares of Calcisols, than of the average of the zone. This finding suggest, that cereals and oil crops are the main plants in the rotation, with legumes and root crops playing a smaller role, just like maize, which is less considered in this soil than on others.

Figure 7a. Dissimilarity indices matrix of cropping systems by RSGs in the Mediterranean (temperate and sub-oceanic) climate zone



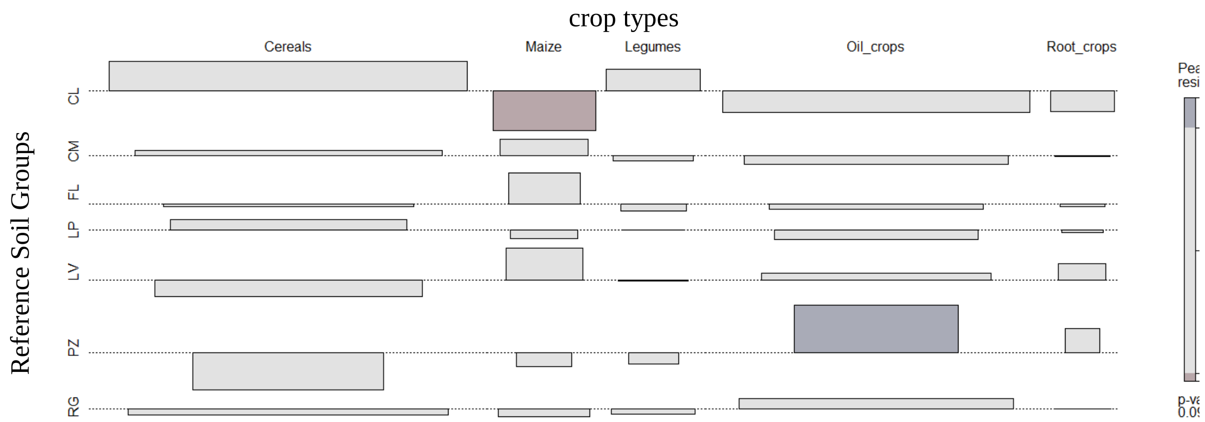


Figure 7b. Conditional association plots of cropping systems by RSGs in the Mediterranean (temperate and sub-oceanic) climate zone

Results of the Chi square statistics:

- *Calcisols are significantly different from FL, LV, PZ (and almost from CM and RG),*
- *Podzols are significantly diff. from CL, CM, LP (and almost from FL)*

at 0.05 level.

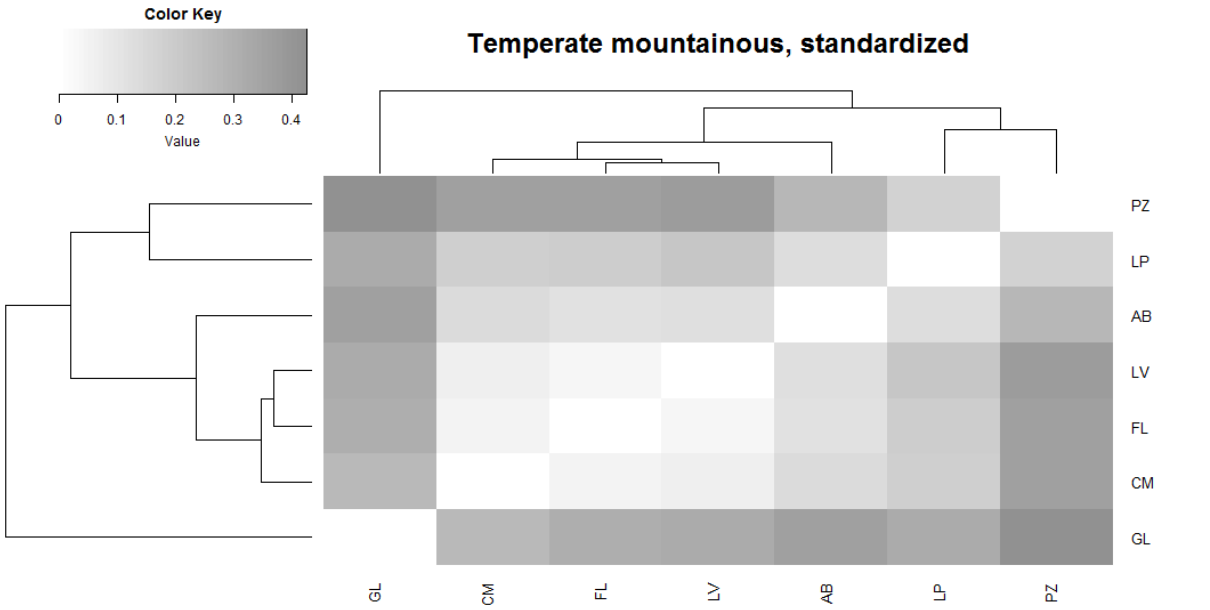
3.7. Comparative assessment of crop systems on different soils of the Temperate mountainous climate zone

Gleysoils are significantly different from all other soil types, due to their lower share of oil crops area and higher share of root crops (Figs. 8a, 8b). One explanation for these findings might be related to the soil geographical and genetic origin of Gleysols. In mountainous areas Gleysols are mostly located on plots with flat topography, where underground water causes reducing conditions. Cultivated Fluvisols of river valleys in this zone can have similar conditions, apart from the constant groundwater influence resulting gleyic properties. While Fluvisols show similar cropping pattern to that characteristic for the whole of the climate zone, Gleysols are used significantly less for oilcrop production and more for rootcrops. We belive that this is due to two reasons. On the one hand, Gleysols are not very suitable for rapeseed (the most common oil crop in this climate zone), particularly if the reductive layer is at shallow to medium depth, because rapeseed needs rather deep rooting zone free of hydromorphism. Rapeseed requires good, fertile soil with high or medium pH values and it doesn’t tolerate compacted soils. These two phenomena are characteristic for the Gleysols in the mountainous regions of Europe. Furthermore long winter and excessive snow cover, which are frequent in this region, are not desirable. Because of the unsteady level of the yield, the successful cultivation of this crop is not assured.

On the other hand potato (the most common rootcrop in this climate zone) finds suitable compartments on Gleysols where gleyic properties are below the top soil layer. Potato appreciates cool temperature and balanced climate and tolerates soil acidity too. However, this crop demands good soil management, for which the technology and traditions are available in this region. Regarding climatic conditions sugarbeet production in general can be successful too and Gleysoils might be suitable to grow the beet after ameliorative soil management, including drainage (as the most important action to reduce the influence of water) loosing, liming and good seedbed preparation.

One should also always keep in mind that agricultural land is rather rare in this climate zone of mountainous land. Therefore local cropping practices – which traditionally are geared towards satisfying local consumption mainly of potato – can diverge the overall picture to a great degree. Rootcrops on Gleysosls are concentrated in the Northern Alps and the central Carpathians. Over-presentation of root crops in this climate zone (table 8b) is due to the wide-ranging potato cultivation on these areas with relatively higher share of agricultural land, compared to other areas in this climate zone.

Figure 8a. Dissimilarity indices matrix of cropping systems by RSGs* in the Temperate mountainous climate zone (*RSGs covering agricultural area above 1% share within the climate zone are assessed)



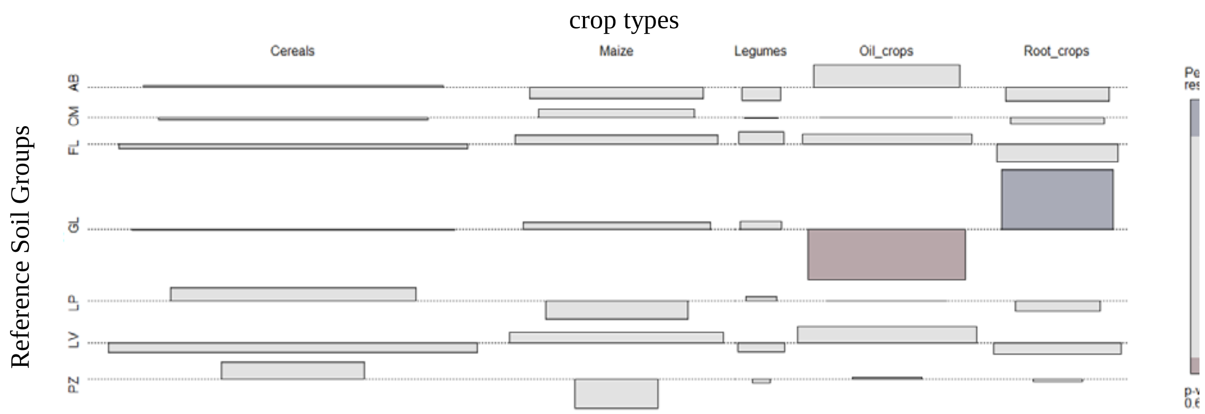


Figure 8b. Conditional association plots of cropping systems by RSGs* in the Temperate mountainous climate zone (*RSGs covering agricultural area above 1% share within the climate zone are assessed)

Results of the Chi square statistics:

- *Gleysols are significantly different from all other RSG at 0.05 level.*
- *Other RSG are not significantly different from each other.*

4. Crop systems in relation to pedoclimatic conditions in China

The analysis of crop systems in the pedoclimatic zones was performed by main climate zones. Map of figure 1. shows the main climate zones in China.

4.1. Comparative assessment of crop systems on different soils of the Mid-subtropical climate zone

According to the statistical comparison displayed also in the evaluation matrix (Fig. 9a), cropping pattern of Anthrosols and Acrisols differs from those on most other soil types. For Anthrosols and Acrisols, there could be found a lot rice, root crops and vegetables. Anthrosols soil was mainly associated with long-term human activity, such as from irrigation and the addition of organic waste. Acrisols soil is clay-rich, and is associated with humid, tropical climates. From the viewpoint of climatic and fertility suitability, high share of crops on Anthrosols and Acrisols would present the difference from cropping on other soils. However, these two RSGs are not different from others (Figure 9b). One potential reason is that the ownership of the fields in this area was very scattered (only a few tenths of hectares), in which there are large population and little farmland. Anthrosols considered to be the best soils in the region, with good structure, favourable water retention and conductivity characteristics and rich nutrient reserves.

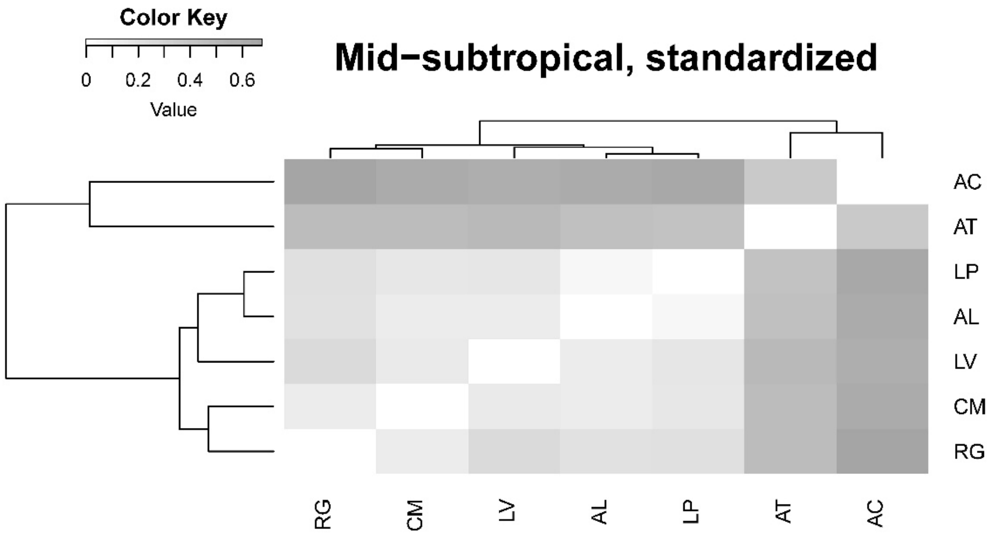


Figure 9a. Dissimilarity indices matrix of cropping systems by RSGs in the Mid-subtropical climate zone

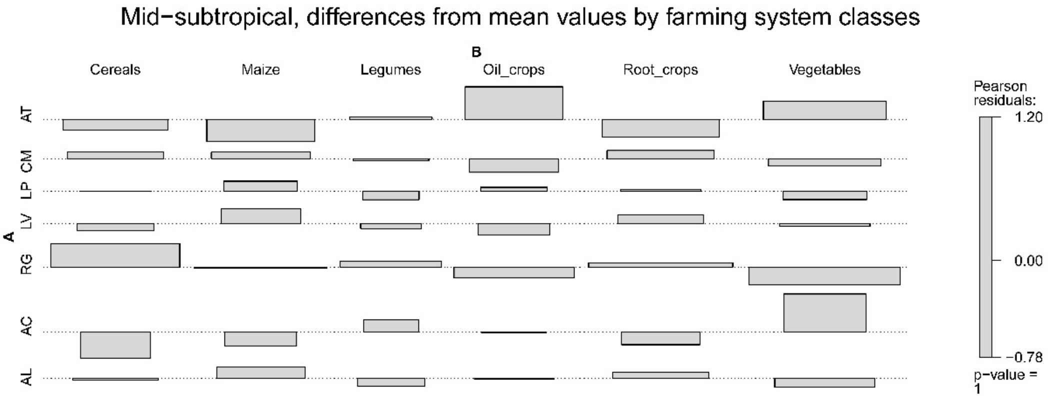


Figure 9b. Conditional association plots of cropping systems by RSGs in the Mid-subtropical climate zone

Results of the Chi square statistics:

- *RSG are not significantly different from each other.*

4.2. Comparative assessment of crop systems on different soils of the Middle temperate climate zone

According to the statistical comparison displayed also in the evaluation matrix (Figure 10a), Kastanozems and Solonchaks are the two soil types of which the cropping pattern differs from those of most other soils in the Middle temperate climate zone (Figure 10a). Furthermore the cropping pattern of Chernozems, Cambisols and Fluvisols is different from those of Phaeozems, Luvisols and Gleysols, while the cropping pattern of Anthrosols does not present the difference from cropping on other soils.

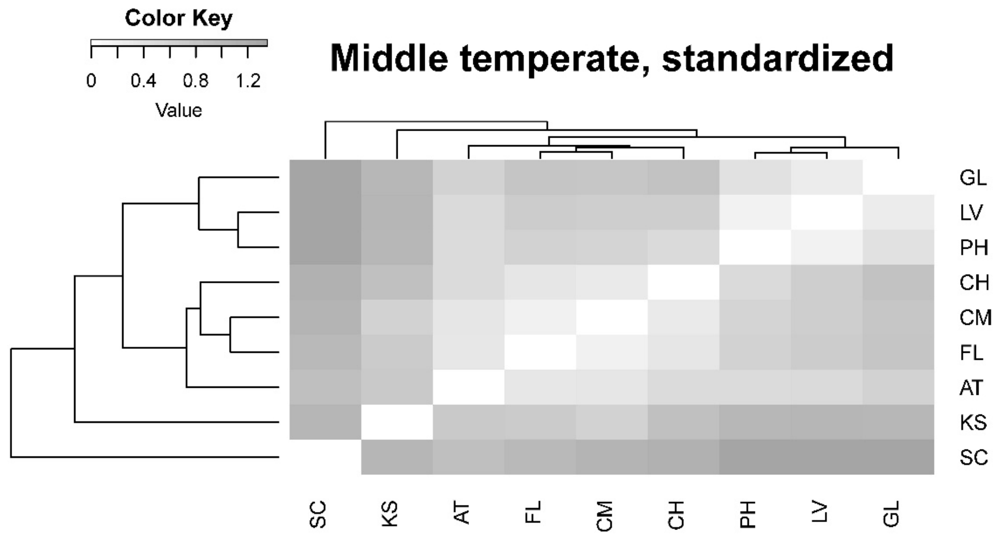


Figure 10a. Dissimilarity indices matrix of cropping systems by RSGs in the Middle temperate climate zone

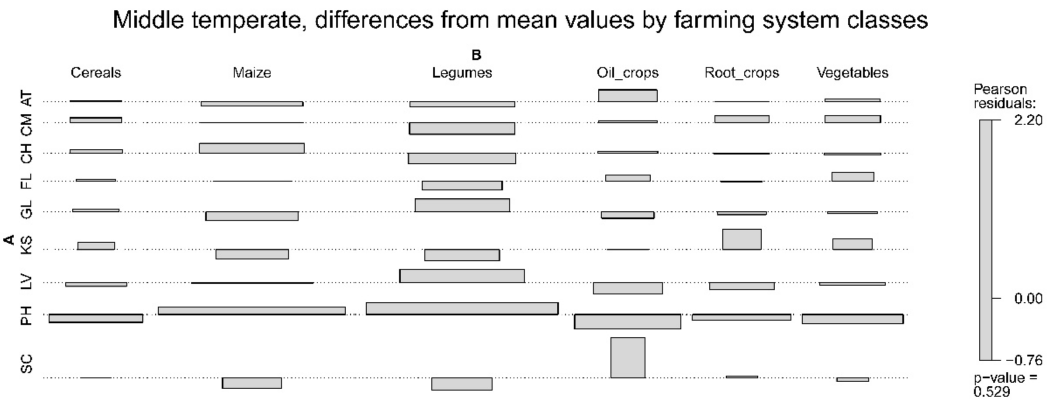


Figure 10b. Conditional association plots of cropping systems by RSGs in the Middle temperate climate zone

Results of the Chi square statistics:

- *RSG are not significantly different from each other.*

4.3. Comparative assessment of crop systems on different soils of the Northern subtropical climate zone

In the Northern subtropical area, the cropping pattern of Alisols is significantly different cropping pattern from other soil types except Regosols, Anthrosols and Gleysols. Acrisols is slightly different with Planosols (Figure 11a). It is noted that the areal share of crops of Fluvisols is the highest, and most areas of those soil types are widely planted with vegetables. In this area, Anthrosols and Luvisols are the typical soil types with the areal are of 31% and 25%, respectively. However, those two soil types present various similarity versus other soil types.

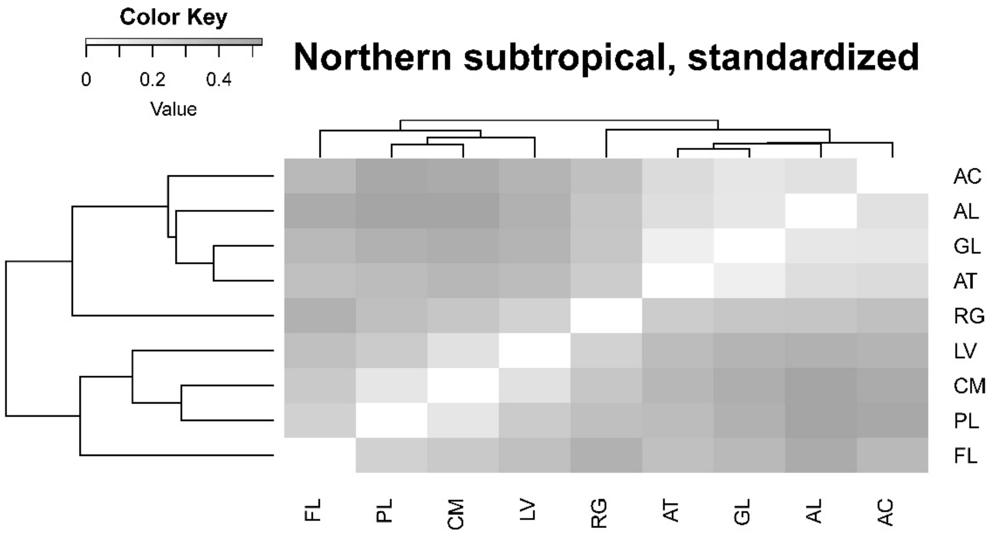


Figure 11a. Dissimilarity indices matrix of cropping systems by RSGs in the Northern subtropical climate zone

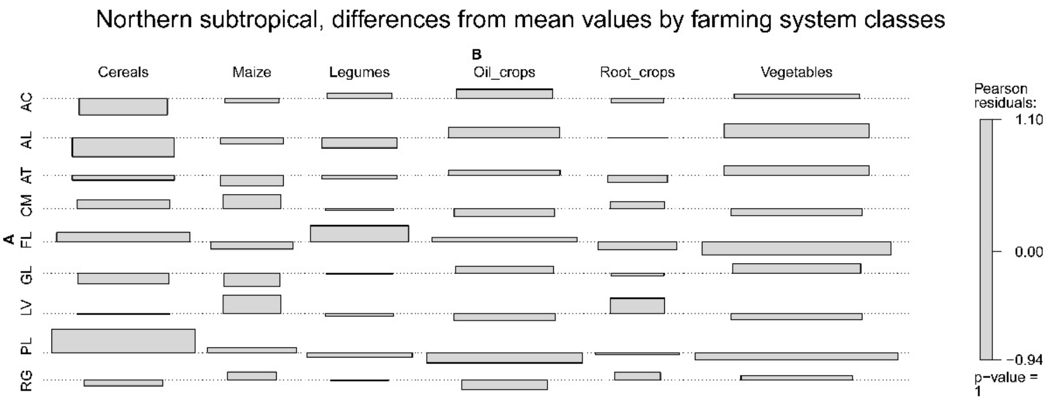


Figure 11b. Conditional association plots of cropping systems by RSGs in the Northern subtropical climate zone

Results of the Chi square statistics:

- *RSG are not significantly different from each other.*

4.4. Comparative assessment of crop systems on different soils of the Southern subtropical climate zone

Luvisols, Alisols and Leptosols are the three soil types of which the cropping pattern differs from those of most other soils in the Southern subtropical climate zone (Figure 12a). It should be pointed out that the areal share of Acrisols of this zone is 65%, in which the main crop types are root crops and vegetables. Formation of Acrisols occurs under climatic conditions that favour both leaching and intense weathering. These conditions are common in regions with a wet tropical or subtropical climate. The acidity of Acrisols is greater in the surface horizons, where it is normally less than 12.5. Therefore, agricultural use of Acrisols is limited chemically by low fertility. Liming and fertilization are the management practices necessary for the production of reasonable agricultural yields.

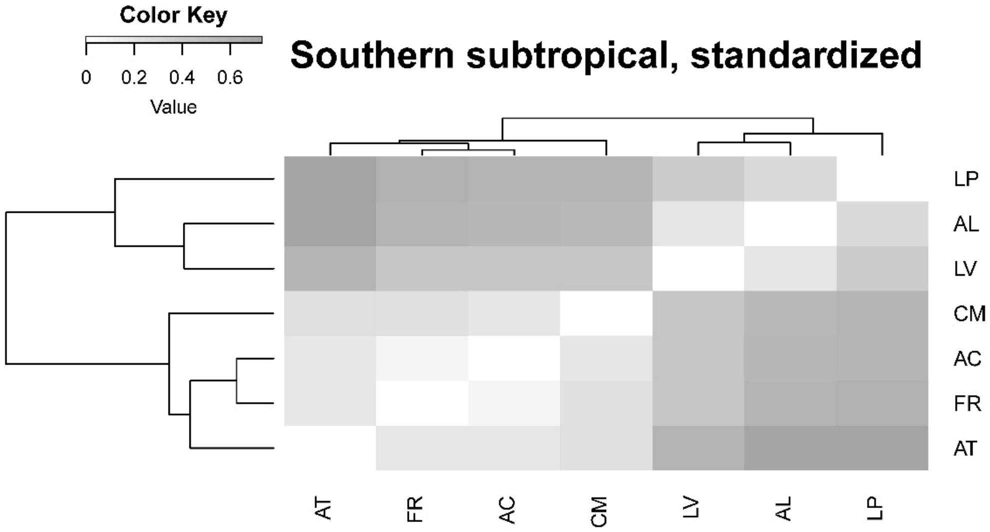


Figure 12a. Dissimilarity indices matrix of cropping systems by RSGs in the Southern subtropical climate zone

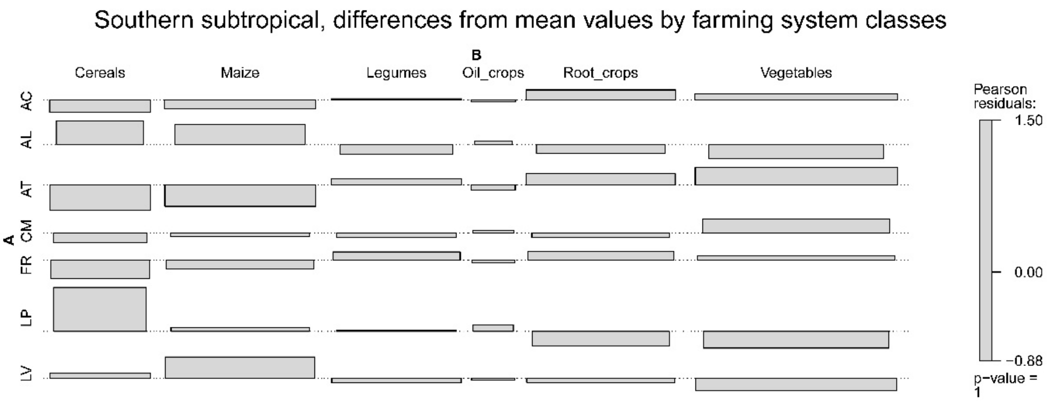


Figure 12b. Conditional association plots of cropping systems by RSGs in the Southern subtropical climate zone

Results of the Chi square statistics:

- *RSG are not significantly different from each other.*

4.5. Comparative assessment of crop systems on different soils of the Tropical climate zone

In the Tropical area, the cropping pattern of Andosols is different cropping pattern from Cambisols and Ferralsols (Figure 13a). Distribution of crops on Regosols differs from that on Anthrosols, Cambisols and Ferralsols. Andosols are soils of active volcanic areas and have a limited extent of Chinese cropland. Andosols is suitable for cultivation due to the favourable physical condition, but the coarse layers of tephra can impede unsaturated water flow. Good quality products are often associated with Andosols, such as of wine. The most typical soil types are Ferralsols, Acrisols and Cambisols, of which the areal shares of tropical climate zone are 28%, 27% and 17%, respectively. Characterized with low agricultural potential, Ferralsols could be improved by anthropogenic disturbance in terms of highly technical interventions and with high levels of investment. Ferralsols soils are very friable and are easy to manage and present a low CEC and quick drainage, in which problems with lixiviation of certain nutrients, as K, can occur. Cultivation on the Acrisols would exposes soils to significant erosion, in that Tropical climate zone usually has a large annual precipitation.

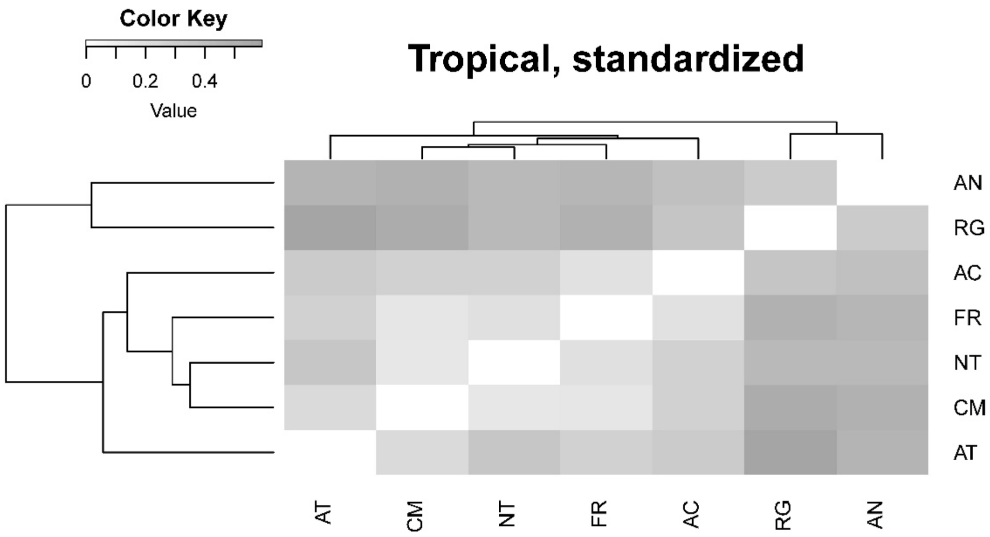


Figure 13a. Dissimilarity indices matrix of cropping systems by RSGs in the Tropical climate zone

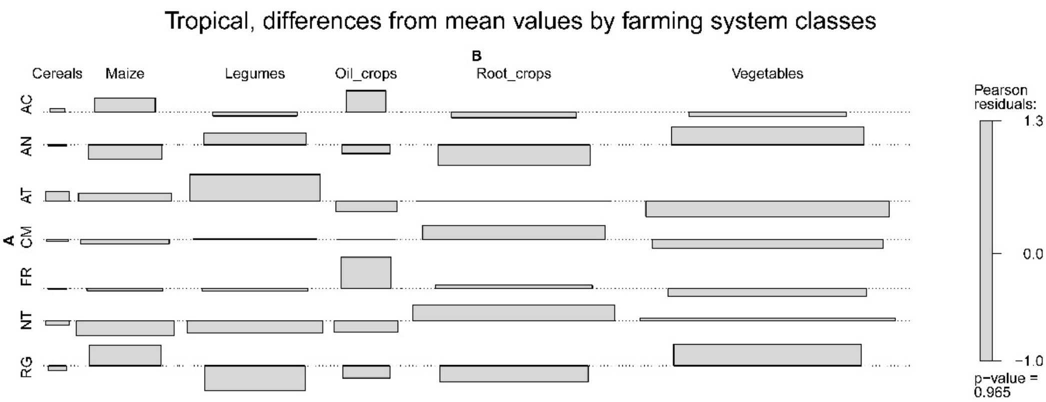


Figure 13b. Conditional association plots of cropping systems by RSGs in the Tropical climate zone

Results of the Chi square statistics:

- *RSG are not significantly different from each other.*

4.6. Comparative assessment of crop systems on different soils of the Warm temperate climate zone

Great variability of crop distribution by soil types is found in the Warm temperate zone (Figure 14a). Especially Andosols and Regosols show divergence from other soil types in their cropping patterns. According to the soil type selection criterion, soil type should occupy at least 1% of the area of target climate zone and of which at least 10% is cultivated. Both of those two RSGs are not the main soil types of this climate zone. The dominant difference of Andosols and Regosols among other soil types and their small areal share might indirectly result in the insignificant differences found in Figure 14b.

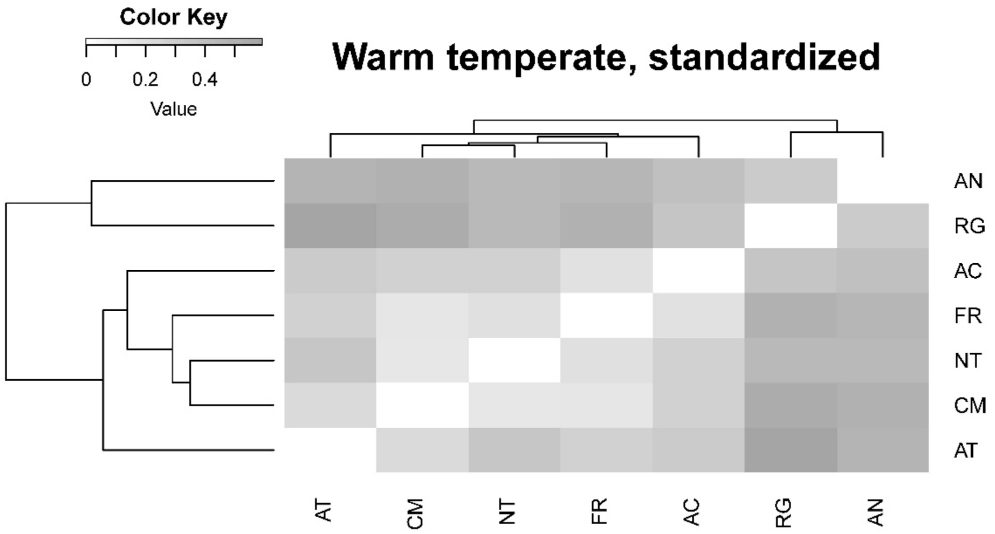


Figure 14a. Dissimilarity indices matrix of cropping systems by RSGs in the Warm temperate climate zone

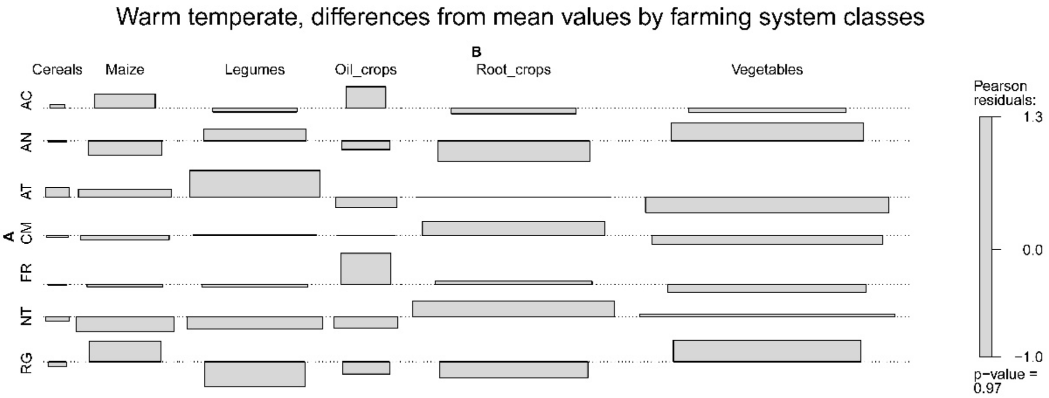


Figure 14b. Conditional association plots of cropping systems by RSGs in the Warm temperate climate zone

Results of the Chi square statistics:

- *RSG are not significantly different from each other.*

5. Discussion and conclusions

5.1 Europe

Our analysis highlights the main features of farming by soil in Europe. Results suggest, that farmers are, in general, consciously take pedoclimatic condition of farming into account when selecting their cropping patterns. In other words, farming by soil is a common practice in the different climatic regions of Europe.

Pedoclimatic conditions are considered in their complexity by the farmers. For instance oilcrops are cultivated on relatively high share of Podzols in Mediterranean (temperate-sub oceanic) and low share of Podzols in southern sub-continantal zone, meaning that similar specific soil conditions are considered together with the prevailing climatic conditions. Other good examples of soil-based farming include rootcrop production on Histosols in the Atlantic climate zone, maize production on Gleysosls of the Southern sub-continental climate, cultivating cereals on Podzols of the Sub-Oceanic climate zone, which all can be regarded as a “farming by soil” practice, which is also recognized on this coarse scale of analysis.

The fact that both zonal and azonal soils are among the soil types that might be cropped differently from the main cropping pattern of the given regions show that apart from climatic factors soil conditions have dominant role in selecting the most suitable crop.

However, we have strong reasons to believe that soil suitability-based cropping is not practiced to its full potential over the continent at the moment. For example our finding suggests that production area of legumes are not always adapted till their full potentials for the local pedoclimatic conditions in some zones. We assume that the reason for this is not always the balanced placement with regular return after long periods of legumes to crop rotation, but because legumes considered mostly “only” as an internal crop between the preferred ones. Legume crops have positive rotational effects that need to be evaluated at rotational level. The reduction in the use of mineral N fertilizers in legume-supported rotations due to biological N2-fixation is the main resource benefit, which, in addition reduces greenhouse gas emissions too. Pea and Faba beans for example are relevant alternatives to soybeans in the European cropping systems and livestock diets, since they can be grown across Europe in the different pedoclimatic zones. Probably including legumes to the rotations based on pedoclimatic conditions would enhance the overall agronomical output. However, cropping desirable from agronomic viewpoint is not necessarily meet the profitability targets of the farm enterprises. In order to utilize the positive agronomic and environmental benefits, the remaining gross margin deficit of legumes should be compensated or further improved e.g. with the development of new value chains and markets, improvements in agronomy and breeding. Nevertheless, the agronomic and economic performance of legumes can only be adequately evaluated when all rotational effects are taken into account.

When comparing our findings with time series statistical data of crop cultivation (Eurostat 2017) we can assume that tendencies driven by policy incentives or climate change can restructure the crop composition of pedoclimatic zones rather rapidly too. Findings of farming in pedocimatic zones under the Atlantic climate underlines that economic drivers are decisive when farmers adopt their cropping (eg. oilcrops on Albeluvsiols), however soil suitability is considered too and may result in win-win situations for the economic return of crop production and management based on soil suitability (roorcrops on Histosols; cereals on Arenosols).

In conclusion, we can assume that pedoclimatic conditions of cropping are respected in most of Europe. Farmers crop according to edaphic conditions whenever economic considerations do not override the ecological consideration of farming.

5.2 China

Obviously, the farming activity in China is generally conducted on reasonable soil types according to the long agricultural history. Our results revealed the difference of main soil types in each pedoclimatic zone regarding crop types. For various climatic zones, agricultural use of soil would give rise to different problems that should be paid extra attentions to. For example, in the tropical climate area, Ferralsols could be improved by highly technical interventions and the intensive use may lead to compaction problems due to their aggregate and pore morphology. Furthermore, Ferralsols soils are very friable and are easy to manage and present a low CEC and quick drainage. Cultivation on the Acrisols would exposes soils to significant erosion, in that Tropical climate zone usually has a large annual precipitation.

Generally speaking, the cropping patterns of all the soil types are not significantly different with each other according to the Chi square statistics. There are two potential reasons for the insignificant difference: 1) some soil types with small areal shares present dominant difference versus other soil types; and 2) the ownership of most croplands in China was very scattered (only a few tenths of hectares) due to the large population and little farmland. Meanwhile, utilized physical area data for crops that were calculated from the MapSpam 2005 dataset (You et al., 2014) regarding pedocimatic zone. The spatial resolution of MapSpam 2005 is 5 arc-minute grid cells (about 10 km).Therefore, there are high uncertainties in the input data.

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