EIP-AGRI Focus Group

Water & agriculture: adaptive strategies at farm level

MINIPAPER: Diversification “Spatial Crop Suitability Indexing”

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Introduction and rationale

Diversity is an inherent property of plant life, of agricultural and natural ecosystems, apparent from plant genetics up to landscape and global level. Adapting to this natural diversity, agricultural regime has evolved during the human history with numerous diverse management choices, cultivation systems, plant species and their varieties, amelioration and treatments and many other numerous options to mention here.

Climate and water availability, as an important regulating factor controlling agroclimatic potential (Grieser et al, 2006), has a tremendous influence not only on past or current agronomic methods, but also on the human population distribution on earth. For example, rainfed agriculture, which still produces today a vast amount of the world's cereals, is adapted in various geographic areas based on the diversification of the plant species and their varieties used, on varying the seeding dates, cultivation mechanisms and so on. Therefore diversification, as an adaptation option of agriculture to climatic variability has been applied for centuries.

As an inherent trait of the agriculture practice since the early days of humanity, there are various applied methods and research for diversification, such as crop rotations, intercropping, plant breeding and new varieties, irrigation application which can significantly increase plant suitability for a given location, various regimes of agroforestry, mixtures of pastures/beekeeping with other agricultural uses, to name just a few. Conservation Agriculture and Ecological Farming can be combined with any diversification method also, so the resulting possible options are numerous.

IPCC reports (IPCC, 2007) and relevant other work provides data (ENSEMBLES, 2003; IPCC, 2016) and information on climate change scenarios. Existing climate risks will be intensified particularly in areas of current water scarcity of Europe (Ciscar at al, 2011), as studies report for the Eastern Mediterranean (Körner at al, 2005). The estimated general regional trend is towards more xerothermic conditions. Agriculture, as an economic activity highly reliant on weather and climate will be the first to be affected from any change.

Furthermore, in the case that even highly productive lands of the Mediterranean will be in an adverse condition, we can expect that the conditions will be more adverse in the areas which are classified as Less Favoured Areas (LFA) based on EC terminology (DG-AGRI, 2009). In these *"areas designated as "less-favoured", agricultural production or activity is more difficult because of natural handicaps, e.g. difficult climatic conditions, steep slopes in mountain areas, or low soil productivity in other less favoured areas".*

Under this hypothesis, these less productive lands of the Mediterranean region, which are already at an exposed status, could be more vulnerable. And, since agroclimatic limitations are expected for Southern Europe (Trnka et al, 2011; Iglesias et al, 2011; Körner et al, 2005), more geographical areas could face harsh conditions. Developing tools today to face current difficulties will help to develop more cost efficient methods for the future, for any region needed.

The question on matching crop requirements to farm characteristics

Dealing effectively with local climate variability and with scenarios of climate change, and adapting agriculture management to it, is also a matter of financial resilience. Highly productive systems naturally receive the attention of experts and research, and generate large capital outputs from which a farmer can dedicate a part of it for expert diversification advice. On the other hand, highly productive lands may be more dependent on production success and capital availability.

In addition to the above, farmers of less privileged regions may be falsely oriented on cash crop and selected varieties of highly productive areas which are also more popular, while their location may not be as suitable for these. While popular irrigated area cash crops may seem attractive due to the large production potential, these may not be a fitting answer for all locations. Productivity and profits can be significantly reduced below the break-even point from an unsuitable investment on a high input crop.

In brief, we could theorize two main reaction trends when a farmer, based on local climatic variability, observes lower than average and even non profitable agricultural returns for certain years: 1) Assuming financial resilience, invests more into buying more land, mechanical equipment, irrigation infrastructure and weather/water use monitoring gear, soil amelioration and fertilization activities, pest management substances and other measures, and acquiring expert opinion on diversification. 2) Or, we could assume that tries to adapt

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to current agroclimatic xerothermic conditions with an extensive management system. However, since main cash crops have lower productivity in such an area (compared to more productive locations), needs specific guidance on which crops and agriculture land uses can be suitable.

Answering these questions is where research and expert opinion can play a significant role, and this is a complex task, requiring analysis from fields of agroecology, climatology, and of course market and marketing research. It is a challenging task, because not only ecologically suitable species need to be screened, but also marketable and financially profitable for growers.

Crop Suitability Indexing

Very common questions regarding farming in general and diversification in particular, can be related to:

- The selection of appropriate species based on the climatic and site conditions of a farm location,
- And, from the land manager's point of view, effective dissemination of information to farmers and stakeholders

To systematically assess crop suitability, estimate potential yield, and efficiently guide farm production is of course a complex and lengthy assignment. Governmental Organizations, universities and research centers, local Agricultural Directorates of the EC Countries are the experts for this purpose in each country.

But, what if another approach is needed, for example to quickly assess a crop not studied extensively before? Or, what if a farmer or another stakeholder with limited resources wishes to swiftly review a plant species climatic suitability prior to any other actions? In all cases, it would be beneficial an initial estimation, which may be followed by more comprehensive examinations later on.

Based on extensive literature review on plant species requirements, Ecocrop (FAO, 2000) is a plant record database which can be used freely online to find matching plants for a specific environment, learn their absolute and optimal growth climate and soil conditions, and identify alternative species.

Developed modelling software tools (Hijmans et al, 2001; Ramirez-Villegas et al, 2011) can be used to carry out an assessment and produce climatic suitability maps, with input climatic data and plant requirement variables. The applicability of this tool is universal, and therefore can be used for any terrestrial location in the world with input climatic and agronomic variables, which are mentioned in more detail below. The climatic suitability assessment carried out below is build on these scientific tools (Hijmans et al, 2001) and climate data (Hijmans et al, 2005) and their importance is greatly acknowledged.

Introductory description of the modelling exercise

A simple case scenario of using EcoCrop modeling tool can include the following actions:

- Define an area of interest
- Choosing a few species to be investigated including their requirements of temperature and precipitation
- Select a dataset of climatic conditions to be used
- And, finally perform the suitability analysis for the desired area

Climatic data sources

Climatic data of monthly temperature and precipitation (Hijmans et al, 2005) is the input for this assessment. It is available globally at various spatial resolutions. Obviously, input data characteristics are directly related to the output resolution and spatial accuracy. For example, if the desired output suitability maps are desired at a 1km resolution, then the input datasets of temperature and precipitation should have that same resolution.

Plant characteristics input requirements

For climatic suitability assessments, the key variables per species are provided and explained in detail in literature. In brief, there are three categories of input plant variables needed, related to length of growing season, temperature and precipitation.

In more detail, as described in related literature, the required input to carry out an assessment for a plant species there are 12 variables required to execute a climatic assessment.

- For growing season length, the number of Growing Season Days is needed, as also the maximum and minimum level of this index.

Temperature input includes the following variables per plant, in Degrees Celsius:

- Killing temperature;
- Minimum and maximum optimum temperature and also minimum and maximum absolute temperature for plant growth.

A third category of variable input is related to precipitation, in units of millimetres (mm). The key variables per plant used here are:

- The requirements per species of minimum and maximum optimum precipitation, minimum and maximum absolute precipitation

Selected plant species for analysis

The assessment is carried out for a few selected species for this assessment, suitable for hilly and mountainous areas also. Obviously, any interested user can carry out a similar investigation for other species for which required input variables are available. The three species examined at this point are:

- Juglans regia, the European walnut: A multipropose tree, that produces drupes (walnuts), high quality timber, also considered suitable for agroforestry.
- Trifolium subterraneaum, a trifolium species: examined here as another forage biomass crop. Can be an excellent ground crop also.
- Olea europea, the common olive tree, cultivated all over the Mediterranean for its products.

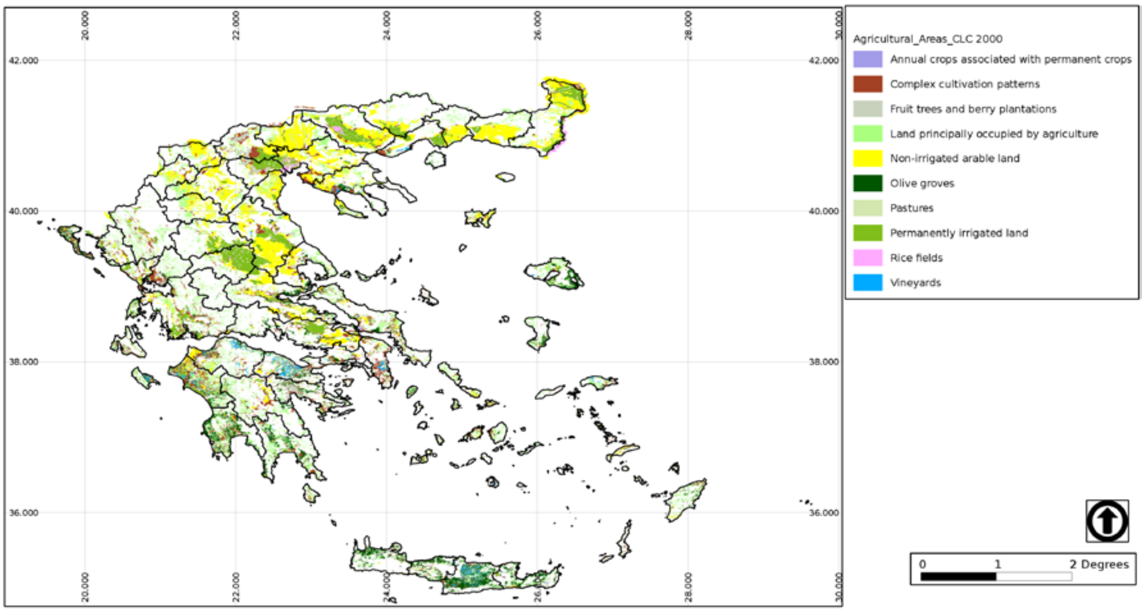
Climatic Suitability assessment

The demonstration assessment is carried out for agricultural areas of Greece, based on CLC 2000 Dataset (EEA, 2012). Corine Land Cover 2000 (CLC 2000) is a dataset by European Environment Agency (EEA). The dataset has, among others, categorizations on agricultural land cover for the EU countries (see the example for Greece in Figure 1).

Global climate data (Hijmans et al, 2005) of 1km resolution was used as input. Specifically the variables used are:

- Minimum monthly temperature;
- Maximum monthly temperature;
- Monthly mean precipitation sum.

Figure 1: Corine Land Cover 2000 dataset (CLC2000), Agricultural Areas, for the country of Greece



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Datasets were reprojected to a common geographical projection system in order to be available for further operations. The climatic data mentioned was used as input into software tools (Hijmans et al, 2001; Ramirez-Villegas et al, 2011), to derive climatic suitability for the plant species considered. Finally, all derived spatial data was assembled as map layouts (QGIS, 2004) for a comprehensive visual demonstration (Figures 2-4).

This approach can be used in various other ways, for example, given the climatic data for an area, find which species are suitable, or find alternatives of known suitable species, without any prior assumption on species selection. The method can be applied on terrestrial ecosystem land globally, and thus can be used as a rapid assessment tool on climatic plant suitability.

Figure 2: Climatic Suitability of European walnut (Juglans regia) for CORINE 2000 Agricultural Areas, for a location of Eastern Central Greece

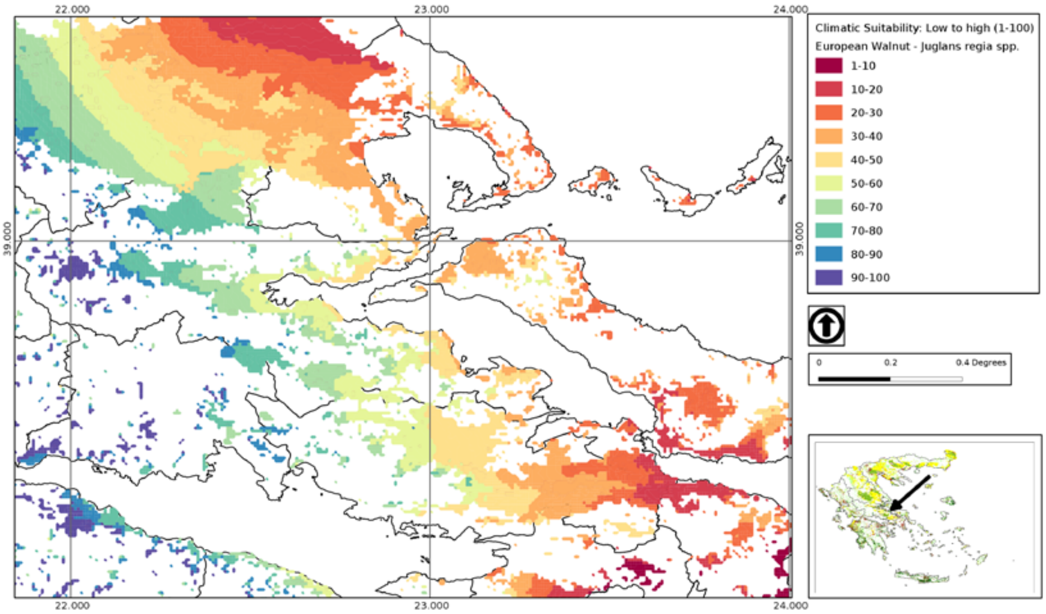

Figure 3: Climatic Suitability of olive tree (Olea europea) for CORINE 2000 Agricultural Areas, Eastern Central Greece

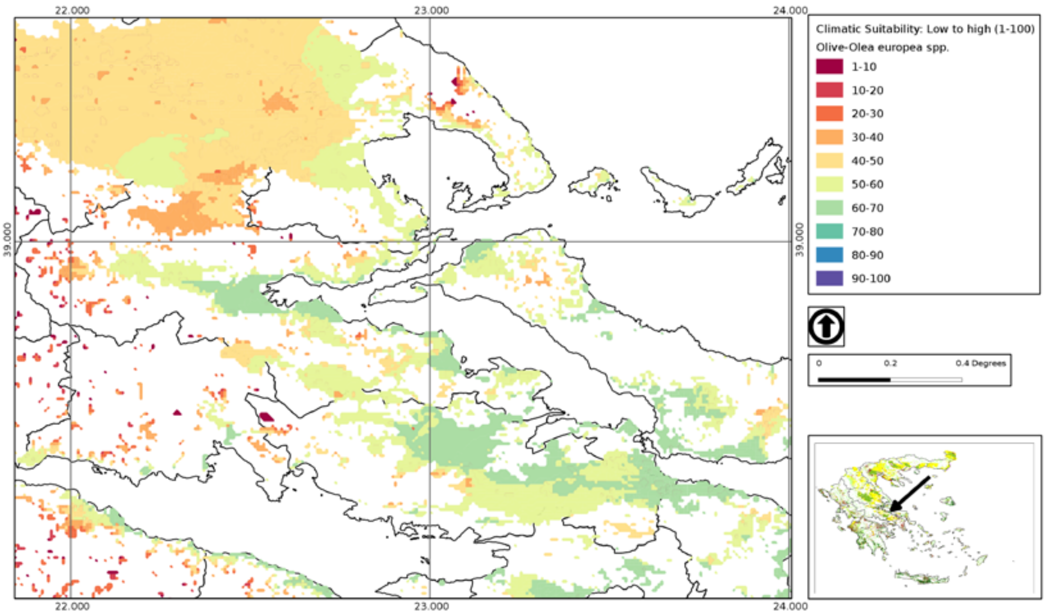

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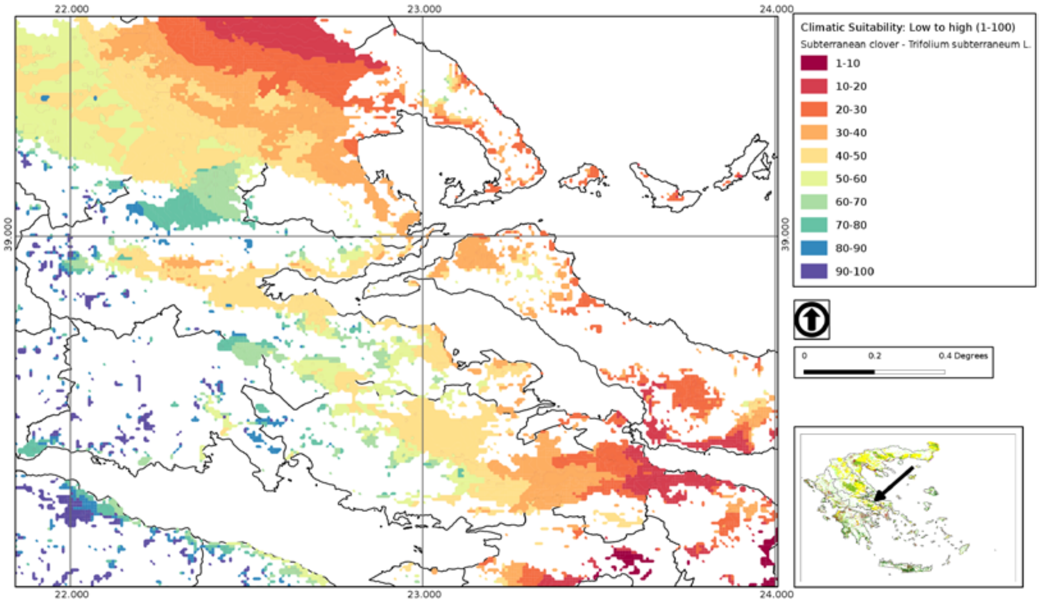
Figure 4: Climatic Suitability of Subterraneum clover (Trifolium subterraneum L.) for CORINE 2000 Agricultural Areas, for a region of interest at Eastern Central Greece



Research needs from practice

The two major inputs of the climatic suitability approach presented are the Climatic data sources and Plant requirements figures. As presented, there are numerous options, data and resources available to potential users in order to carry out a similar assessment. Extending the approach beyond the databases already provided can lead to two research needs, related to both input categories.

Key variables for new species or varieties

What if interested parties wish to use the approach for a new crop variety, or for a currently undocumented in the Ecocrop Database plant species? In that case, crop variables related to Growing Season Length, Precipitation and Temperature are needed. These can be assessed by various ways, such as by literature review, expert opinion, or scientific research. Then, figures can be used as described to carry out model calibration and execute climatic suitability assessments.

Alternative climatic data sources

Also, another question can arise in case user wishes to use a different, other than the already provided climatic data sources. For example a user wishes to employ a climatic dataset produced at a lower or higher resolution, or for a different climatic period. The answer to such a need is the development of a new climatic data with the desired characteristics for the input variables. For example, a user can develop custom datasets based on local or national climatic data available from the National Meteorological Services. Also, there are several datasets to choose from at the international level for current (Hijmans et al, 2005) or future conditions, and also are Global Climate Model (ENSEMBLES, 2003; IPCC, 2016) data available. Please note that any custom datasets should be re-formatted to be used as software input. When the above data research needs are addressed, the method and tools presented can be calibrated, to accommodate user requirements and carry out suitability assessments with the new crop and/or climate data.

Links to Operational Groups

Diversification options on matching plants to certain geographic areas, for choosing crops or crop varieties, can be assessed and optionally compared with existing field methods or scientific proposals made under detailed investigations on field. Obviously, the Operational Group Proposals related to Diversification and specifically to Crop Suitability Indexing are strongly linked to the approach discussed in this paper.

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Additionally, the method presented can be used as an option to assess suitability for species prior to any field trials and other modeling efforts, and it is in line with OG proposals under Farm Resilience and particularly with species evaluation studies.

Dissemination of results to stakeholders

Based on the draft climatic suitability analysis above, maps produced can be distributed to interested parties in hardcopy or digital format, as a visual means to disseminate complex information in a simple manner. In general, farmer education and training can play a crucial role to the success of agricultural diversification, and this goal can be achieved and with the use of ICT means available today.

Assumptions and caveats

It is important to stress out that the current demonstration assessment is providing results of climatic suitability solely, and does not account for other environmental factors, such as influence of soil types, soil water holding capacity and various other variables. Other environmental drivers can significantly influence the suitability of a geographic location for plant life, and can account for large variations in plant growth. More elaborated studies and/or locally customized crop growth models can be used if exhaustive assessments are desired.

Conclusions

Answering the crop diversification question for various geographic areas can be a challenging task, and there are multiple modeling and expert options to complete this. Communicating such composite information to practitioners and decision makers in a straightforward layout is also of crucial importance.

Combining both questions, an effort was carried out at this point out to demonstrate a methodology and tools developed by the international scientific community which can help, among others, solve desertification questions and efficiently disseminate results.

References

Ciscar, J.-C., Iglesias, A., Feyen, L., Szabó, L., Regemorter, D. Van, Amelung, B., ... Soria, A. (2011). Physical and economic consequences of climate change in Europe. Proceedings of the National Academy of Sciences, 108(7), 2678-2683. http://doi.org/10.1073/pnas.1011612108/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1011612108

DG-AGRI. 2009. "Rural Development Policy 2007-2013 - Aid to Farmers in Less Favoured Areas (LFA)." http://ec.europa.eu/agriculture/rurdev/lfa/index_en.htm.

DG-AGRI. 2009. "Rural Development Policy 2007-2013 - Aid to Farmers in Less Favoured Areas (LFA)." Map of Less Favoured Areas. http://ec.europa.eu/agriculture/rurdev/lfa/images/map_en.jpg.

ENSEMBLES Project, 2003. Contract number GOCE-CT-2003-505539, FP6

European Environment Agency, Corine Land Cover 2000 seamless vector data, http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-4, 22-08-2012

FAO. "Ecocrop." FAO of the UN, Rome, Italy http://ecocrop.fao.org/ecocrop/srv/en/home.

Hijmans R. J.; Cameron S. E.; Parra J. L.; Jones P. G.; Jarvis A. (2005). The WorldClim interpolated global terrestrial climate surfaces.

Hijmans, R. J., Guarino, L., Cruz, M., & Rojas, E. (2001). Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. Plants Genetic Resources Newsletter, 127, 15-19. http://doi.org/10.1016/j.compositesa.2008.10.018

Iglesias, A., Mougou, R., Moneo, M., & Quiroga, S. (2011). Towards adaptation of agriculture to climate change in the Mediterranean. Regional Environmental Change, 11(SUPPL. 1), 159-166. http://doi.org/10.1007/s10113-010-0187-4

IPCC Data Distribution Centre, 2016 http://www.ipcc-data.org/

IPCC. (2007). IPCC Fourth Assessment Report (AR4). IPCC, 1, 976. http://doi.org/ISSN: 02767783

Körner, C., Sarris, D., & Christodoulakis, D. (2005). Long-term increase in climatic dryness in the East-Mediterranean as evidenced for the island of Samos. Regional Environmental Change, 5(1), 27-36. http://doi.org/10.1007/s10113-004-0091-x

Jürgen Grieser, René Gommes, Stephen Cofield and Michele Bernardi New gridded maps of Koeppen's climate classification. The Agromet Group, SDRN FAO of the UN, Viale delle Terme di Caracalla, 00100 Rome, Italy http://www.fao.org/nr/climpag/globgrids/kc_classification_en.asp

Quantum GIS (QGIS) version 1.7.5 Wroclaw, QGIS Development Team, 2004 www.qgis.org

Ramirez-Villegas, J., Jarvis, A., & Läderach, P. (2011). Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. Agricultural and Forest Meteorology, 170(0), 67-78. http://doi.org/10.1016/j.agrformet.2011.09.005

Trnka, M., Olesen, J. E., Kersebaum, K. C., Skjelvåg, A. O., Eitzinger, J., Seguin, B., Peltonen-Sainio, P., Rötter, R., Iglesias, A., Orlandini, S., Dubrovský, M., Hlavinka, P., Balek, J., Eckersten, H., Cloppet, E., Calanca, P., Gobin, A., Vučetić, V., Nejedlik, P., Kumar, S., Lalic, B., Mestre, A., Rossi, F., Kozyra, J., Alexandrov, V., Semerádová, D. And Žalud, Z. (2011), Agroclimatic Conditions In Europe Under Climate Change. Global Change Biology, 17: 2298–2318. Doi:10.1111/J.1365-2486.2011.02396.X

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