# Development of comparable agro-climatic zones for the international exchange of data on the efficacy and crop safety of plant protection products[1]

E. Bouma

*Plant Protection Service, Geertjesweg 15, PO Box 9102, NL-6700 HC Wageningen (Netherlands); e-mail: e.bouma@minlnv.nl*

Data on the efficacy and crop safety of plant protection products can be used for registration purposes in other countries, provided crop growth conditions are comparable. This article identifies the main conditions which are relevant in this respect, with particular emphasis on climatic conditions. Comparison of several systems of agro-climatic classification developed for the EPPO region, particularly the climate diagrams of Walter & Lieth, the climate classification system of Köppen & Geiger, the agro-climatic areas of Thran & Broekhuizen and natural vegetation maps, has led to a division of the EPPO region (Europe, Mediterranean area, Middle East) into four agro-climatic zones (Mediterranean, Maritime, North-east, Central) within which conditions can be considered comparable.

## Introduction

The main purpose of EPPO Standards on the efficacy evaluation of plant protection products is to harmonize the process of efficacy evaluation within the registration procedures of EPPO member countries, by describing how field trials should be conducted. More recently, these standards have taken on formal importance within the registration process of the European Union through their adoption under Directive 91/414 (EU, 1993). This includes the requirement that organizations conducting, developing and carrying out efficacy and phytotoxicity trials in EU member states are officially recognized by governmental bodies.

The published EPPO standards have also facilitated an important secondary aim, which is to use data generated in one country to support registration in another country. Since the introduction of Directive 91/414, applicants in the EU and EPPO generally are now beginning to generate data for the efficacy dossier of a product on a Europe-wide basis. In addition, there is a specific provision under Article 10 of the Directive for the mutual recognition of authorizations from other member states. In establishing a Europe-wide dossier or in mutual recognition, not only must trials be conducted according to harmonized procedures, but the registration authority must also establish whether the data is relevant under the local conditions, i.e. whether the appropriate conditions (see below) are comparable in the countries concerned, particularly in relation to climate.

This paper presents basic principles on the effects of climate on pest/crop interrelationships. It suggests broad categories for these parameters within the EPPO region, and defines zones within which conditions could be considered climatically comparable. Applicants may refer to these defined zones when addressing climate comparability, rather than making a detailed case. Moreover, climate is only one factor that may affect the efficacy and crop safety of a product. The applicant may still need to address other factors (agronomic, edaphic, target-related) when establishing the relevance of data generated within different countries (see Other relevant factors). Even when there are significant differences in climate or other factors, extrapolation may still be appropriate if the conditions in the country where the application is made are deemed to be at least as challenging as those in the country where the product is already authorized.

## Principles

### Agriculture and climate

Meteorological conditions before, during and after application of agrochemicals are very important for both efficacy and crop safety. Also, the speed of growth and development of plants and crops, and of pests, is strongly influenced by meteorological parameters. Although micrometeorological circumstances can differ within small areas (Bouma, 1999, 2003) and although micrometeorological data is recorded before, during and after application of products in efficacy trials, it is better, when comparing areas, to use data on climate, because:

"Climate is the synthesis of weather events over the whole of a period statistically long enough to establish its statistical ensemble properties (mean value, variation, probabilities of extreme events, etc.) and is largely independent of any instantaneous events." (Essenwanger, 2001)

[1]The Figures in this Standard marked 'Web Fig.' are published on the EPPO website www.eppo.org.

In order to assess the importance of climate at different localities for any kind of trials, it is necessary to establish what relationships exist between the growth of specific crops and their pests and the values of certain climatic elements. Climatic elements of high importance for the efficacy and phytotoxicity of plant protection products, for the germination and growth of weeds and for rate of development of other pests are: temperature (mean, minimum, maximum), relative humidity[2], precipitation, radiation and wind (direction and velocity).

Most crops show distinct differences, within their area of distribution, in many of their properties, for example in phenological data, growth, yield and quality. The chief cause of such differences is to be sought in variations in climate. Even fairly small variations in a single climatic element can exert an obvious influence, for example in relation to cultivars of a given plant. These differences need only occur during a few growth-controlling periods, and plants are affected not only by differences in the single climatic elements but also by various combinations occurring simultaneously or in succession. For this reason, the usual division of Europe into a few areas with distinct values of the main climatic elements is inadequate from the point of view of agronomy. By taking into account all the climatic elements and making a more detailed classification of their respective values, it is possible to divide Europe into numerous subareas, each with its narrowly differentiated 'general type of agroclimate'.

### Variety of climates in Europe

Europe extends over 30 degrees of latitude in a north–south direction, which means that incident sunshine releases very different quantities of energy in different areas of Europe, particular during certain seasons. The very broken coastline in the south, west and north also plays an important part in determining the distribution of temperature and rainfall from west to east. All climate maps shows this multiplicity. In relation to crops, the main points of interest are: rainfall (during the growing period), temperature (mostly only temperature in the growing period, but for some crops, temperature throughout the year), frost-free periods and humidity.

*Rainfall*

Average annual rainfall is abundant nearly everywhere in Europe and in some areas of the Middle East. However, in the mountains, it is much heavier than in the surrounding lowlands (Walter, 1969). Prevailing winds over most of the area are westerly all the year, but they are stronger and more constant in the north-west. The maritime precipitation furnished by these prevailing moist westerly winds is blocked by coastal mountains in several places, but this only affects the climate locally and does not act as a complete barrier to the precipitation.

The east–west European system of mountains from Spain to the Balkans is, however, an important climatic divide in that it acts as a barrier to the Mediterranean climate from the south, as well as to the maritime climate from the west and north-west.

The broad pattern of central Europe is one of transition from the oceanic north-west of Europe to continental Russia. From west to east, precipitation falls gradually (up to 40% reduction), except where highlands and mountains intervene (though the Atlas mountain ranges of North Africa do not have high average annual precipitation figures).

*Temperature and frost-free period*

Temperature in Europe varies greatly along any parallel of latitude, owing to prevailing winds and variation in altitude. Average temperature decreases as the altitude increases and the rate of decrease is about the same everywhere. It falls about 1°C for every 100 m of elevation. In northern and north-western Europe, and in most of central Europe, the prevailing winds are from the west, and blow straight from the warm ocean, which is a more important source of heat to western Europe in winter than the direct rays of the sun. These winds are the cause of the mild, moist and cloudy climate of western and northern Europe. A notable characteristic of the European climate is its lack of extreme variations in a particular area. Along most of the west coast of the continent, the difference between the mean temperature of the warmest and coldest months is less than 6.5°C (Kalb & Noll, 1990).

During the winter months, the centre of Europe is cold, but the north-western part has a relatively high temperature because of the warm air currents coming in from the ocean. The coldest part of Europe in January is in the north-eastern part of European Russia and the North of Scandinavia, while the warmest areas in winter are the Mediterranean islands and the tips of Mediterranean peninsulas. In some northern regions of Europe and Asia, the amount of radiation is a limiting factor in the growing season (Salonen *et al*., 2001).

The term 'frost-free season' is generally used to designate the number of days without killing frost in any region. It is determined strictly by the prevailing temperature conditions, and only expresses what may be called the 'thermal growing season' of a large area. It does not take into account local environmental factors, such as lack of moisture or poor soil. These may prevent a specific crop from being grown in an area, even where the season is satisfactorily frost-free (Thran & Broekhuizen, 1965).

## Climate comparability

### Definition of zones

*Division of Europe into agro-climatic subareas*

Many authors have published climate classification systems and maps showing the limits of the various climates, main climatic types, climatic types, climatic subtypes and transition climates. A review of this work was given by Essenwanger (2001). Classification of climate is a grouping of atmospheric

[2]Use of water vapour pressure would be preferable, because relative humidity is influenced by temperature. However, relative humidity is easy to measure and, in some cases, it is the driving force of natural and phytopathological processes.

conditions for locations which show similar climatic conditions (climate types) separated by defined boundaries applied to one or more meteorological elements (Essenwanger, 2001).

None of these classification systems is based on all climatic elements affecting the crop. A map was accordingly constructed showing all boundaries between areas of different climates within Europe. In this way, it should be possible to use all climatic parameters influencing crops and pests. The boundaries proposed are essentially those described by Köppen & Geiger (1928, 1936), and also those of Miller (1953), Thornthwaithe (1948), Gorczynski (1948), Vahl & Humlum (1949), Troll (1958), Walter & Lieth (1960), Troll & Pfaffen (1963), Thran & Broekhuizen (1965), Holdridge (1967) and Okolowicz *et al*. (1992). In mountainous areas, the variety of climatic factors makes it impossible to give a general characterization for the entire zone.

*Climate diagrams*

Walter & Lieth (1960) produced climate diagrams from many meteorological stations throughout the world. These are brief summaries of average climate variables and seasonal variation. The diagrams display monthly averages for temperature and precipitation and the seasonal patterns over a year. They also give an idea of the duration of cold/warm or wet/dry seasons and the extent of their fluctuations. Since all the diagrams are plotted on the same scale, it is possible to compare moisture, temperature and other environmental conditions in widely separated parts of the world.

By using the diagrams (Web Fig. 1; Walter, 1969), Walter and Lieth produced a world atlas with 10 principal climate types (Walter & Lieth, 1960). According to this system, the European and Mediterranean region (EPPO region) belongs to regional climates IV (Mediterranean, winter rains), VI (humid, with cold seasons), VII (arid, with cold seasons), VIII (boreal) and X (mountain areas).

The boundaries between the 'general agro-climate' subareas hardly ever represent an abrupt transition from one climatic element to another. Besides, these classification systems are not based on all the climatic elements which affect crops, and in most cases they make no contribution to the solution of agricultural problems. Hence the present division into 'general agro-climate' subareas does not represent any new grouping but is a 'projection' on a single map of the divisions as conceived by Thran & Broekhuizen (1965).

*Climate classification system*

Köppen & Geiger (1936) made a climate classification system based on a quantitative system of temperature and amount of precipitation (Web Fig. 2). The Köppen system distinguishes six major types of regional climate (A, B, C, D, E, H), which are further divided into subcategories. The subcategories BW and BS take vegetation into account, and a further subdistinction between 'k' and 'h' distinguishes hot (h) from cool (k) climates. According to the Köppen system, the European and Mediterranean region (EPPO region) belongs to regional climates C (moist climates with mild winters), D (moist climates with severe winters) and H (highland climates). Plants were used as meteorological instruments for measuring precipitation effectiveness and drainage to make the regional climates (Table 1): Bhw, BWh, Cfa, Cfb, Csa, Csb, Cfa, Dfa, Dfb, Dfc (Schneider, 1996; Essenwanger, 2001; Kraus, 2001).

**Table 1** Classification of the EPPO region according to the Köppen Climate Classification System

| | |
|---|---|
| BWh | Tropical desert, hot arid |
| BSk | Mid-latitude steppe, semiarid, cool or cold |
| Cfa | Humid subtropical, moist all season, hot and long summer, mild winter |
| Cfb | Marine, moist all season, warm summer, mild winter |
| Csa | Interior Mediterranean, mild winter, hot summer, summer dry |
| Csb | Coastal Mediterranean, mild winter, warm summer, summer dry |
| Dfa | Humid continental, moist all season, hot summer, cold winter |
| Dfb | Humid continental, moist all season, warm summer, cold winter |
| Dfc | Subarctic, short summer, cold winter, winter dry |
| H | Highland climate |

One of the modifications of the system of Köppen & Geiger was made by Strahler owing to air-mass source regions and their zones of contact. Strahler's modification is based on latitudinal and coastal locations of places (Strahler, 1963; Rumney, 1968; Barry & Chorley, 1968). He developed three groups of latitude climates, divided into 15 groups in all. This is a modification of a plant distribution system that first appeared in the USDA Yearbook (Blumenstock & Thornwaite, 1941), conforming to the principle that the presence and form of natural vegetation are mainly attributable to the qualities of the atmosphere. An easy way to recognize a climatic region is through its effect on the predominant groupings of plants that grow on the surface of the earth (Web Figs 3 and 4).

An important modification of the basic principles of Köppen has been made by Thran & Broekhuizen (1965), by placing emphasis on the relevant time of year when evaluating climatic data. Thus, climate data for the winter season is not relevant for the pest problems of spring-sown crops. Only when the winter period is of significant importance to weeds (overwintering, emergence), insect pests (diapause, mortality) or pathogens (overwintering bodies) in relation to the autumn-sown crop or to a long-term crop, is it of major importance to look at the climate data for the full year.

Thran & Broekhuizen (1965) tried to create new agro-climatic subareas, based on the length of the period from spring to midsummer, and from midsummer to autumn. These 'phenological' periods, which provide a suitable basis for evaluating agricultural potential, refer to the period between the sowing of the earliest crop in spring to the sowing of the latest crop in the autumn. It gives some information on the time when spring begins (e.g. when the +5°C mean daily temperature is exceeded and conditions remain frost-free) and the length of the vegetation period. Using the Köppen & Geiger classification system, Thran & Broekhuizen adjusted annual precipitation, annual temperature, summer temperature (warmest month), winter temperature (coldest month), precipitation and photoperiod in up to nine

ranks. With the help of this ranking system, they developed 76 different agro-climatic subareas in Europe (Web Fig. 5).

*Proposed zones*

On the basis of all the information described above, and taking into account natural vegetation maps for Europe and Asia, we have been able to divide Europe, the Mediterranean area and the Middle East into a number of agro-climatic zones[3] (Fig. 6).

The *Mediterranean zone* comprises the countries or parts of countries around the Mediterranean sea, together with Jordan, Macedonia and Portugal. It is the region of 'Mediterranean' plant species, favoured by mild winter and warm summer temperatures with relatively wet winters and dry summers. This corresponds to the region with codes Csa and Csb according to Köppen & Geiger, code IV according to Walter & Lieth, and codes 33–36, 458, 65–75, V–Y according to Thran & Broekhuizen.

The *Maritime zone* is the zone north of the line from the coastal zone of south-west France, through Lyon (France), to the south border of Switzerland and Austria, west of the border between Austria and Hungary, west of the border between Czech Republic and Slovakia, west of the river Oder (between Poland and Germany). This zone also includes Ireland, Sweden and the United Kingdom. It is the region of 'Atlantic' plant species, which grow in moderately cool or cold winters and fairly mild summer temperatures, with relatively wet winters and wet to occasionally dry summers. This corresponds to the region with codes Cfa and Cfb according to Köppen & Geiger, code VI according to Walter & Lieth, and codes 3, 6, 7, 8, 14b, 17, 19–25, 27–33, 39–45 according to Thran & Broekhuizen.

The *North-east zone* includes the countries and the regions east of the river Oder (between Poland and Germany), north of the border between Czech Republic and Poland, west of the border between Poland and Ukraine, north of the border between Ukraine and Belarus, Russia north of 50° latitude. It is the region of 'Continental' plant species that grow in cold relatively wet winters and mild dry summers. This corresponds to the region with codes Dfb and Dfc according to Köppen & Geiger, code VIII according to Walter & Lieth, and codes 1, 4, 5, 14, 18, 60, A, B, E, F, G, I, M, H according to Thran & Broekhuizen.

The *Central zone* is made up of Bosnia-Herzegovina, Bulgaria, Croatia, Hungary, Moldova, Romania, Russia south of 50° latitude, Slovakia, Slovenia, Serbia and Montenegro, Turkey, Ukraine, except the Mediterranean coastal zones. It is the region of 'Continental' plant species that grow in cold relatively dry winters and warm dry to occasionally wet summers. This corresponds to the region with codes Cfb, Dfb and Bsk according to Köppen & Geiger, code VII according to Walter & Lieth, and codes 60–64, P, R, S, N, K, L according to Thran & Broekhuizen.

This zonation is proposed for the comparability of efficacy evaluation data. A similar analysis can be made for data on residues of plant protection products, and results in only two zones (Northern Europe and Mediterranean).

[3]Excluding mountain areas above an altitude of 1000 m.

## Discussion

It is important to stress that the proposed zones present a valid overall picture, despite the fact that the boundaries between them have to be placed with a certain degree of arbitrariness.

In general, the distinction between the different zones, based on agro-climatic data supplied by numerous authors, is supported by vegetation maps. The division of regions and countries in the Mediterranean and Maritime zones is clear. However, the division of the eastern part of Europe into two zones is arguable. Interpretation of vegetation maps (USDA, 1948; Bohn & Katenina, 1993), climate classification maps (Köppen & Geiger, 1936; Haurwitz & Austin, 1944; Troll & Pfaffen, 1963), climate diagram maps (Walter & Lieth, 1960) and the agro-climate areas and subareas of Thran & Broekhuizen (1965) leads to the conclusion that there is a clear difference in agro-climatic circumstances between central and north-eastern Europe. The main differences are the annual precipitation (higher in the North-east zone) and the summer temperature (higher in the Central zone). The North-east zone is characterized by capital B, humid (Köppen) and VIII (Walter) and the Central zone is characterized by capital D, semiarid (Köppen) and VII (Walter).

In conclusion, for the purposes of registration of plant protection products, the EPPO region should be divided into four zones from the agroclimatic point of view.

## Other relevant factors

Climate is only one of the factors to be considered in establishing the relevance of data on the evaluation of plant protection products from one part of the EPPO region to another. Some of the other factors that may need to be considered are presented below. It is not possible to provide a prescriptive list, as this depends on the individual circumstances of use, mode of action, physical and chemical properties of the product, etc. Instead, the case for comparability should focus on factors relevant for performance and crop safety, and for the biology and incidence of the target. Extrapolation between regions may still be valid when the factors differ significantly, provided that the situation, in terms of efficacy and crop safety of the plant protection product, can be considered to be at least as challenging in the area of 'recognition' as in the area of registered use.

### Edaphic conditions

For soil-applied products, it is important to compare soil types, organic matter content and pH. It may also be important to take into account soil moisture content/deficit over the duration of the trial.

### Agronomic conditions

Cultural conditions and agronomy which may need to be considered include soil cultivation, application methods, cultivars, fertilizer regime, times of planting and harvest.

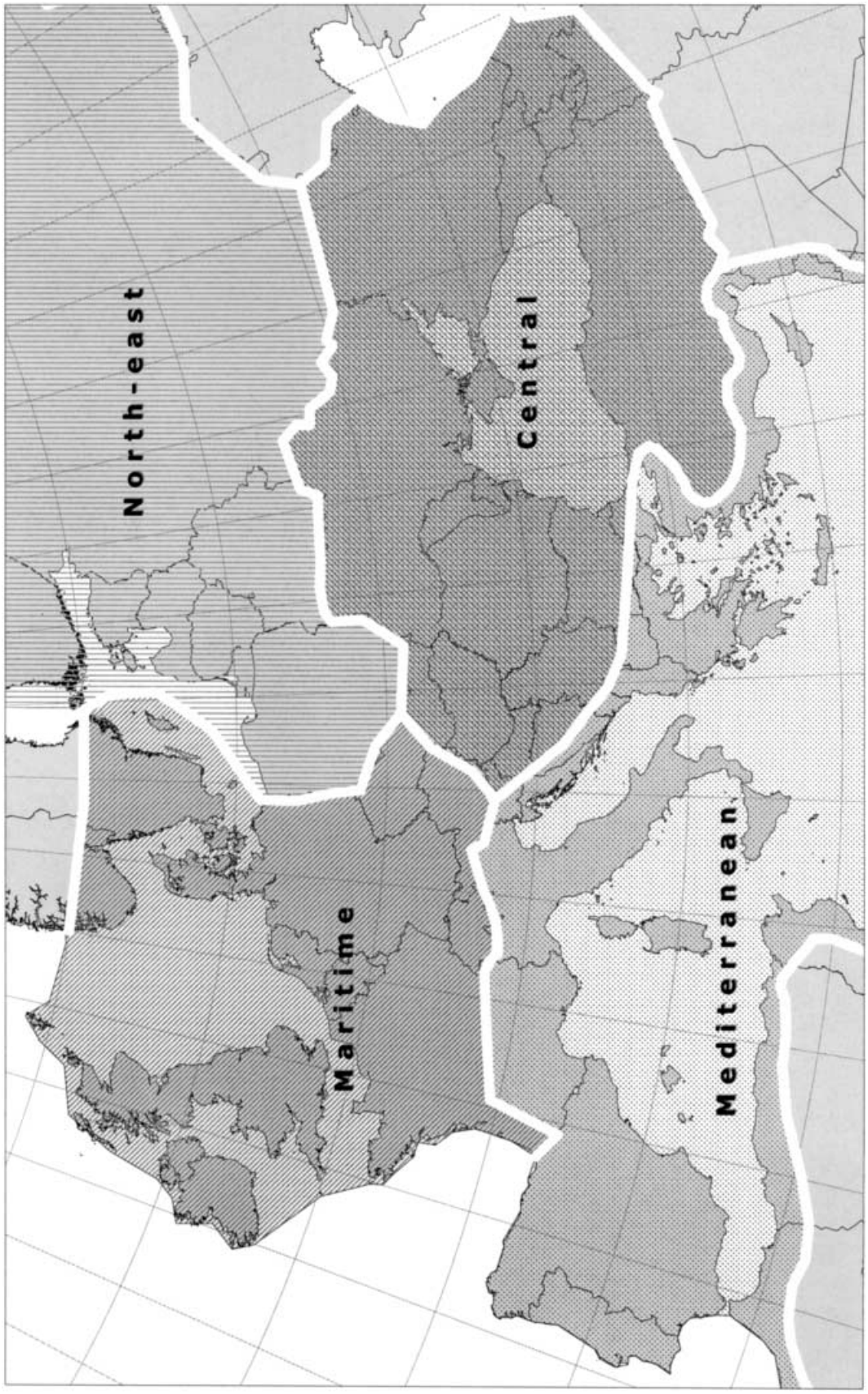


**Fig. 6** Proposed division of Europe, the Mediterranean area and the Middle East into a number of agro-climatic zones, for the purposes of the mutual recognition of efficacy evaluation data of plant protection products. (N.B. the analysis in this paper does not allow a clear division between the Maritime and North-east zones in Norway and Sweden north of the 60th parallel.)

#### Differences in target pest pressure

Certain aspects related to the target pests may give rise to a more or less harsh test of the efficacy and crop safety of the plant protection product. These could include: differences in epidemiology or population dynamics of the pests, different races of the target pest, resistance of pest populations.

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## Développement de zones agro-climatiques comparables pour l'échange international de données sur l'évaluation biologique et sur la sélectivité des produits phytosanitaires

Les données sur l'évaluation biologique et sur la sélectivité des produits phytosanitaires peuvent être utilisées pour l'homologation dans d'autres pays, à condition que les conditions de croissance de la culture soient comparables. Cet article identifie les principales conditions qui sont pertinentes dans cette perspective, en insistant en particulier sur les conditions climatiques. La comparaison de plusieurs systèmes de classification agro-climatiques développés pour la région OEPP, en particulier les diagrammes climatiques de Walter & Lieth, le système de classification des climats de Köppen & Geiger, les zones agro-climatiques de Thran & Broekhuizen et les cartes de végétation naturelle ont conduit à une division de la région OEPP (Europe, zone méditerranéenne, Moyen-Orient) en quatre zones agro-climatiques (Méditerranéenne, Maritime, Nord-est, Centrale) au sein desquelles les conditions peuvent être considérées comme comparables.

## Развитие сопоставимых агроклиматических зон для международного обмена данными по эффективности и селективности препаратов для защиты растений

Данные по эффективности и селективности препаратов для защиты растений могут использоваться для их регистрации в других странах, если условия роста сопоставимы. Статья определяет главные условия, которые подходят к этому случаю, с особым упором на климатические условия. Сравнение нескольких систем агроклиматической классификации, разработанных для региона ЕОКЗР, в частности диаграмм климата Уолтера и Лейта, системы классификации климата Коппена и Гейгера, агроклиматических зон Трана и Брокуйзена, а также карт природной растительности привели к подразделению региона ЕОКЗР (Европа, Средиземноморская зона, Ближний Восток) на четыре агроклиматических зоны (Средиземноморскую, Приморскую, Северо-восточную, Центральную), в пределах которых условия можно считать сопоставимыми.

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