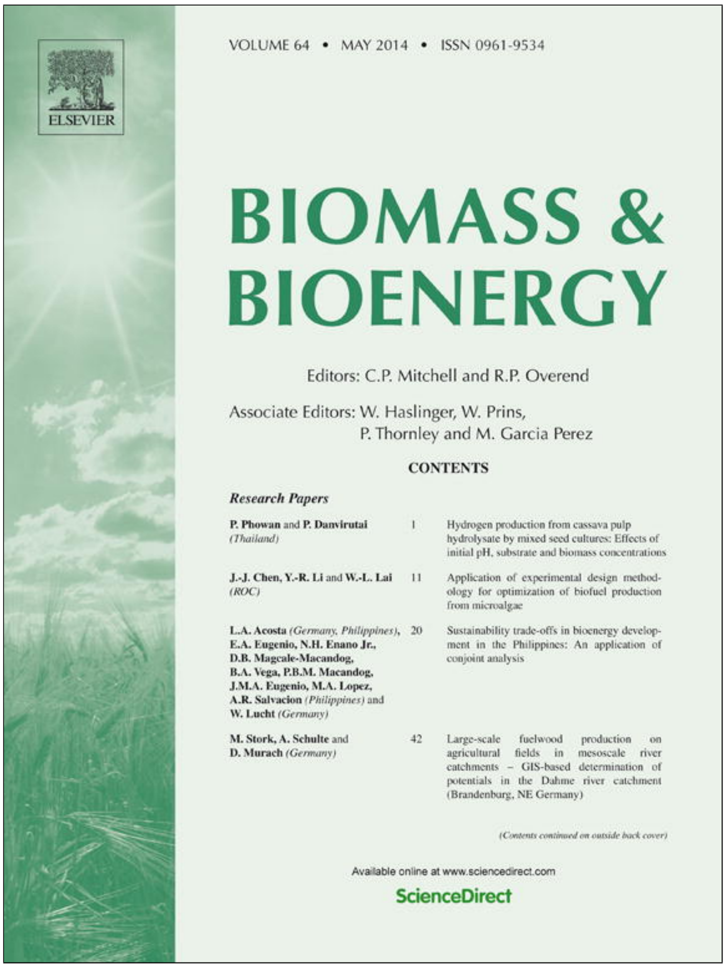
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Possibilities for growing kenaf (*Hibiscus cannabinus* L.) in Argentina as biomass feedstock under dry-subhumid and semiarid climate conditions

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ABSTRACT

Kenaf (*Hibiscus cannabinus* L.) is an annual herbaceous crop with a high biomass production.

In this paper, and based on international bibliography, the authors outline an agroclimatic and agro-ecological zoning model to determine potential growing areas in Argentina for kenaf. The bioclimatic variables considered were: 150 frost-free days, isohyets of 500, 780 and 1200 mm corresponding to November–March (the growing period), a mean annual temperature of 11.5 °C and temperatures of 15 °C, 20 °C, 25 °C and 27 °C during the growing period.

The agroclimatic indices, which determine different classes of suitability, were integrated in a Geographic Information System in order to create thermic and hydric regions. The maps were superimposed, and the overlapping regions delineated the agroclimatic zoning.

Thornthwaite's Moisture Index = 0 was overlapped on the agroclimatic zoning map to guarantee that the lands to be occupied by the proposed energy crop would be located under dry-subhumid, semiarid or arid climate conditions. This last map was superimposed on another one that determined unsuitable soils for traditional agriculture. The overlapping regions defined the agro-ecological zoning for kenaf.

This is an innovative work, made by the implementation of a geographic information system that can be updated by the further incorporation of complementary information, with the consequent improvement of the original database. Furthermore, its focus is not merely local since the model described may be applied to any part of the world, using the agroclimatic limits presented in this paper.

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1. Introduction

Economic and population growth, together with industrialization processes, have led to an increase in energy consumption and demand. The non-renewable sources of energy in the planet are finite and are depleting at a fast rate. In today's society, researchers around the world are searching for ways to develop alternative fuel sources.

A very promising renewable energy source is biomass, which can be used to produce biofuels. However, exploitation of biomass for biofuels is restricted due to the competition of biomass as food/feed or fodder resource. Only non-edible crops have a clear opportunity as a source of biofuels, either as sole block plantations or accompanying food crops.

Furthermore, there is a rising interest in the world for non timber-yielding vegetable species as suppliers of cellulosic fiber. This would defuse potential threats for the paper industry, since bio-refineries and the production of bio-fuels could reduce the availability and increase the price of raw material for this industry in the future [1].

In addition, the negative effects of climate change are clearly observed in the modifications of normal weather cycles. Rainfall dependent agro-ecosystems are increasingly experiencing higher uncertainties in agricultural production.

One of the crops that could surmount the problems mentioned above is kenaf. The productive versatility and agronomical rusticity of kenaf make it a promising species for Argentina. The crop fulfills many purposes and its biomass can be used both in the paper industry (paper pulp) and as an energy source, through thermo chemical processes (gasification) or production of briquettes.

1.1. *General characteristics*

Hibiscus cannabinus L. (Malvaceae) is an annual plant native to Africa that can grow in a wide range of climates and types of soils [2]. This species has several common names: kenaf, bimli, bimlipatum jute, deccan hemp. It is an erect, herbaceous, single stemmed plant and it can reach heights of up to 1–5 m. The plant has been cultivated for more than 4000 years and it is rich in fibers, with a high production of lignocellulosic material.

Kenaf is fast growing and, in barely 4 months, it can reach heights of 3 m, although 6 m-high plants have also been found. For this reason, in tropical and sub-tropical areas, it is possible to obtain up to 2 harvests per year.

1.2. *Uses of kenaf*

Kenaf is mainly grown as a fiber crop, but it is also well known as a biomass crop [3] and for the phyto-remediation of soils [4]. It presents several advantages over other wooden fibers, since the process of transforming the pulp into paper requires less energy and fewer chemicals [5].

When the crop is destined for fiber production, the cultivars must be close to a transformation facility or industry. The fibers, often compared with the ones obtained from hemp (*Cannabis sativa*) or jute (*Corchorus capsularis*), have many applications. They are traditionally used in the manufacture of ropes, bags, cordages, and carpet yarns. In addition, they can also be employed as pulp fiber and for animal grazing. However, they also have many innovative uses, such as the manufacture of paper, wooden products, mats, and absorbent material for oils and liquids. They can also be employed in construction work and in the production of automobile bodies [6].

The paper obtained from kenaf fibers is whiter, more resistant and yields improved results upon printing. For these reasons, the fibers are also employed in the manufacture of recycled paper. They contain less lignin than traditional wooden pulp and this reduces the energetic costs involved in the production process [7,8].

The seed contains between 18 and 35% of semi-dry edible oil [9], a percentage similar to *Arachis hypogaea* (peanut) oil (10). The oil can be used to manufacture soaps, in cosmetic products and in lubricants, linoleum, paints and varnishes. It can also be employed in the production of biofuels and high-value compounds [11].

Several studies have shown that kenaf is a crop with forage potential [12]. The leaves and stalks are appropriate for the diets of ruminants because of their protein content. The leaves alone have 21–34% protein content, while the stalks are in the 10–12% range and the whole plant has levels of 16–23% [12]. This species has successfully replaced the dehydrated alfalfa that is used for feeding sheep [13] and it has also been stored in silages for young bulls and lambs [14]. The equipment to harvest forage for silage has to be modified minimally [15].

In addition, young plants can be used as fodder and young leaves as vegetable. The dried stems can be used as fuel [16].

1.3. *Productivity*

Kenaf can enter into crop rotation cycle as a spring-summer crop. There are many varieties with 60, 90, 120, 150 and 180-day cycles. The length of the growing period becomes crucial if the aim is to obtain biomass.

Kenaf was sowed for the first time in a commercial scale in Argentina in 1995. After the harvest, the material had to be taken to a commercial plant to be turned into pulp and, later, mixed with the bagasse pulp to make paper. Unfortunately, the early summer of 1996 was one of the driest registered in the northeast of Argentina and, at the time, the idea of planting it for commercial purposes was abandoned. In Argentina, yields of more than 17.5 ton/ha of DM have been reached [17]. However, the yields of each independent assay were extremely variable, fluctuating between 4.3 and 13.3 ton/ha, depending on the location and the weather. Furthermore, it was observed that cultivars had similar yields in each particular location tested, indicating that this factor exerts a significant influence and has to be specifically considered when the crop is used for commercial production.

According to [16] total production of green plants may be around 36 ton/ha, yields of fodder from 10 to 14 ton/ha and fiber yields from 1 to 6 ton/ha. Annual seed yields may be about 350–400 kg/ha.

The recollection of stalks presents difficulties because the fibers are hard and have high humidity levels. For instance, in Italy, harvesting is done in winter employing a foliage chopper and using the dry material obtained after the frosts. In Spain,

Fig. 1 – Location of Argentina in the World.

biomass production takes place predominantly at the beginning of autumn. In this case, after the cutting, the material is dried for 10–15 days before it is packaged. Another possibility is to obtain relatively large pieces of stalks with a forage chopper and then proceed to wrap them after they dry. In areas with mild winters, defoliants or desiccants can be used to hasten drying [18].

The commercial uses for the crop deserve special consideration, since the quality of the fiber decreases after flowering and also after the initiation of seed formation. However, this is not crucial when the purpose is to produce lignocellulosic material.

1.4. *Ecological requirements*

Kenaf can be grown between latitudes 45°N and 30°S and can be found at altitudes up to 1250 m or more, under different climatic regimes [20].

The climate zones include: tropical wet and dry (Aw), tropical wet (Ar), steppe or semiarid (Bs), subtropical humid (Cf), subtropical dry summer (Cs), subtropical dry winter (Cw), temperate oceanic (Do), temperate continental (Dc), temperate with humid winters (Df) and temperate with dry winters (Dw) [6].

The cultivated forms are erect herbaceous annuals, grown from 100 to 240 days that can be harvested for fodder after 100 days and for fiber after 120–150 days. To achieve ripeness, they require at least 150 frost-free days [19].

The plant is adapted to a relative air humidity range of 68–82% and it flowers when the day's length shortens to 12.5 h or less. High winds and heavy rain, especially when the crop is near maturity may cause much lodging [16].

Although high temperatures and humidity favor its growth, it nonetheless tolerates droughts [4]. In spite of its prolific root system with lateral roots, it is extremely sensitive to changes in soil moisture [17].

Several authors [23] found that the plants decreased water consumption during the vegetative phase, conserving it for the flowering one. Under water stress, the vegetative phase is extended and flowering is not induced [21,22]. Thus, in areas were water availability by rain or by irrigation is limited, water requirements are not met and yields are negatively affected. This situation is particularly important when seed production is required [4].

Kenaf is a C_3 plant characterized by a highly efficient use of light, and its assimilation proportion is higher compared to others with similar photosynthetic metabolism (C_3). Its use of water is also highly efficient, and it inhabits places with annual rainfalls of 570 mm to 4100 mm and average annual temperatures ranging from 11.1 to 27.5 °C [16,23,24].

Some authors have reported that it grows very slowly with air and soil temperatures lower than 10 °C [10,23,24]. Stem growth can thus be hindered by the cool temperatures of late summer or early autumn [25].

The base temperature (temperature below which plant growth is zero) is 15 °C. The average temperature during the growing season has to be higher than 20 °C. Wood [26] established a critical value of 20 °C, below which kenaf growth ceased.

The maximum assimilation of CO_2 takes place at temperatures between 25 and 27 °C. During the growing season (October to April in the Southern Hemisphere), the plant is sensitive to freezing temperatures, and strong rains and gusts easily damage it. The highest efficiency in biomass is achieved in regions with high temperatures [27].

The cultivation of kenaf is recommended for tropical and subtropical climates, from sea level up to 1000 m of altitude. Temperatures at night must be higher than 18.3 °C and rainfall has to be in the 500–600 mm range, distributed in a period of 4–5 months, alternating dry and humid stages. Optimum growth is obtained with 780 to 1200 mm [4].

It has been reported that long days favor the growth of the fiber while short days stimulate the development of the flowering and fructification stages. In high latitudes, the plant vegetates and does not flower until the day's length is less than 12.5 h/day. If the weather is very cloudy for two

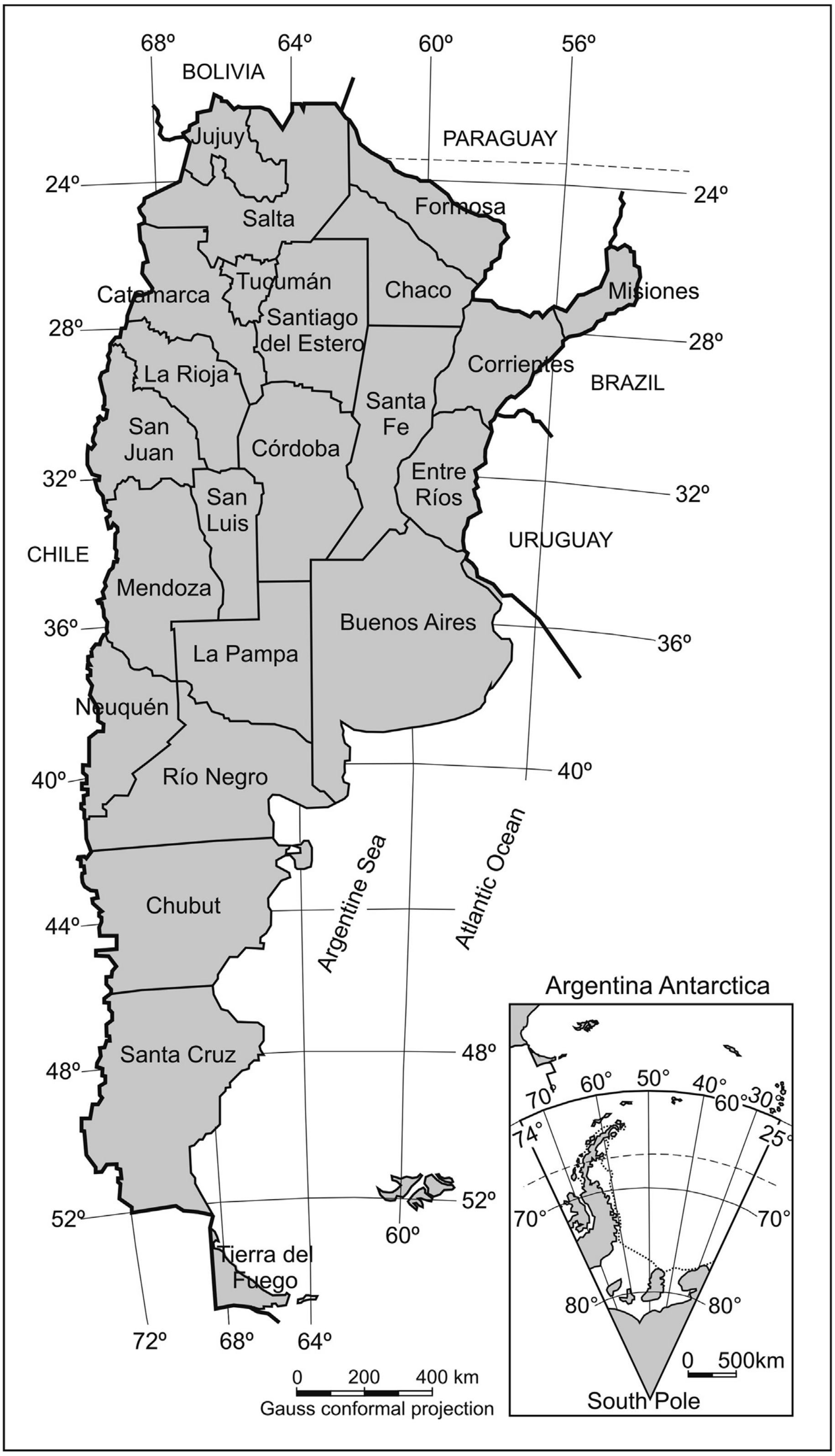

Fig. 2 – Argentina's political map.

consecutive weeks, kenaf flowering will be induced with a photoperiod of 12.5 h [28].

Kenaf adapts to a wide variety of soils, but the best are the ones that are deep, friable, well-drained, sandy loam with humus. Light sandy soils are not recommended. It tolerates pH values of 4.3–8.2 [10]. A neutral to slightly acid pH is recommended [29].

The plant can grow successfully with moderately saline irrigation water. However, salt levels in excess of 4.6 dSm^{-1} in the irrigation water severely restrict plant growth and development and result in significant yield reduction. It tolerates moderately saline soil (EC: 4–8 dSm^{-1}) [30,31], while its requirements of phosphorus and nitrogen are relatively low [32].

The aim of this work consisted in defining the potential growing areas in Argentina for kenaf, as raw material to produce lignocellulosic biomass, under dry-subhumid and semiarid climate conditions.

2. Materials and methods

First, to determine the requirements, limits and bio-meteorological tolerance and conditions for this species, the

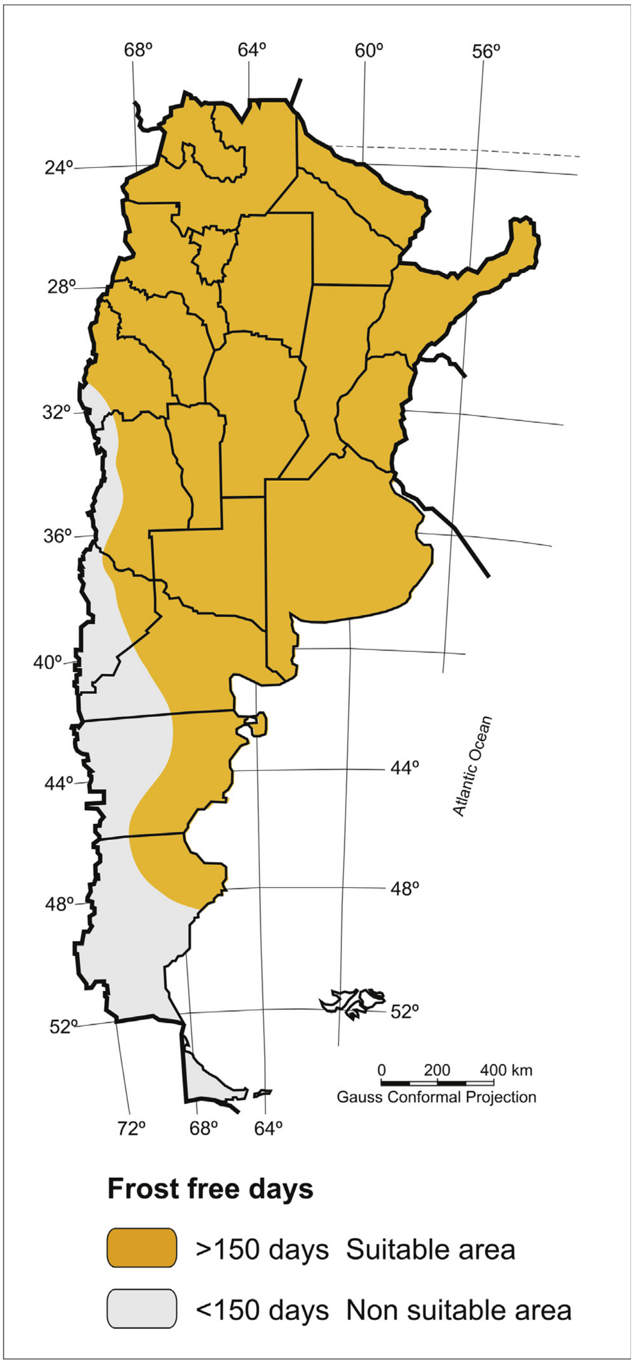

Fig. 3 – Frost-free days.

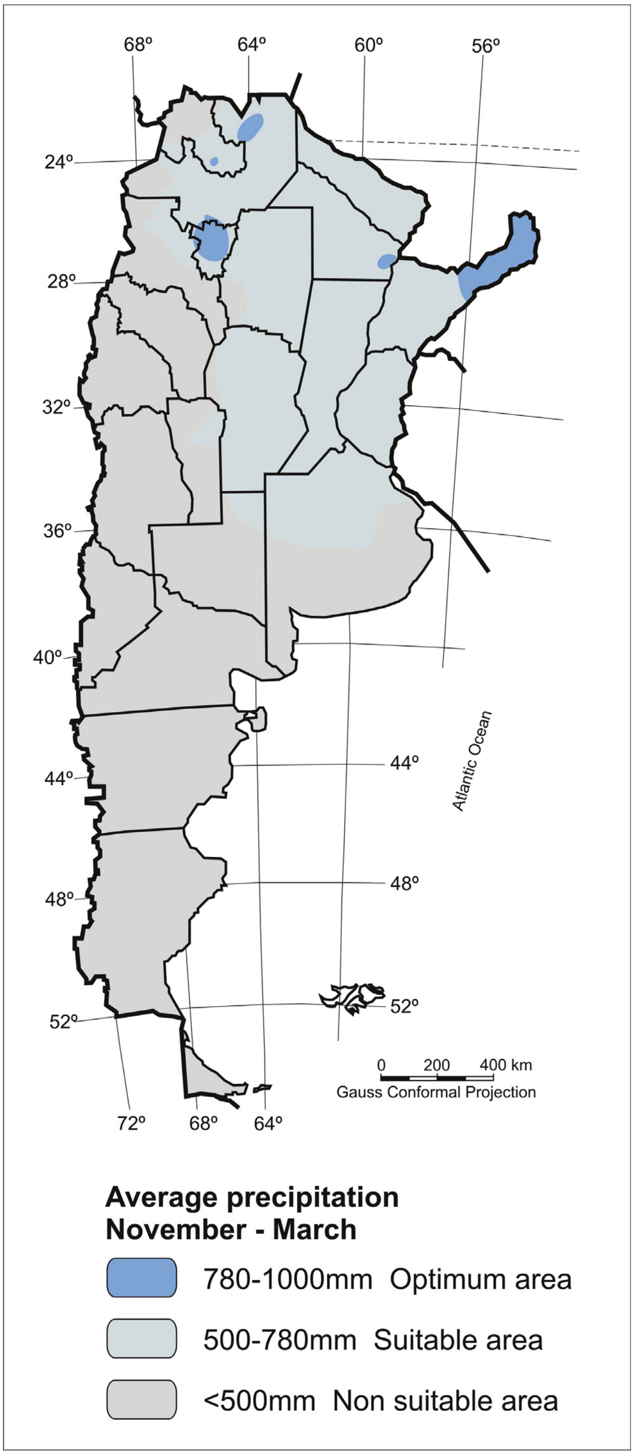

Fig. 4 – Average rainfalls during the growing period (November–March).

climatological characteristics of native areas and the regions of successful cultivation around the world were analyzed. The resulting bio-climatological indicators were extrapolated to the Argentine territory. Growth aspects, such as development and death chances by excess or deficiency, were specifically considered. To define the agro-climatic fitness of *H. cannabinus* in Argentina, the weather data used was the one collected in all the meteorological stations around the country in the period spanning from 1981 to 2010. In parallel, an agro-climatological inventory was performed based on available climatological statistics. When all the information was gathered, the data were evaluated.

The first step consisted in analyzing the frost-free days. The areas with 150 or more frost-free days were considered suitable since, for the production of biomass, the duration of a culture cycle devoid of frosts is a priority.

In order to analyze kenaf's bioclimatic requirements, the focus was turned first on the hydric factor. The average isohyets of 500, 780 and 1200 mm during the growing period were analyzed. The areas that received <500 mm were described as non suitable areas. In the range of 500–780 mm the areas qualified as suitable, and from 780 to 1200 mm, optimal.

When analyzing the thermal factor, the isotherm corresponding to the average annual temperature of 11.5 °C was

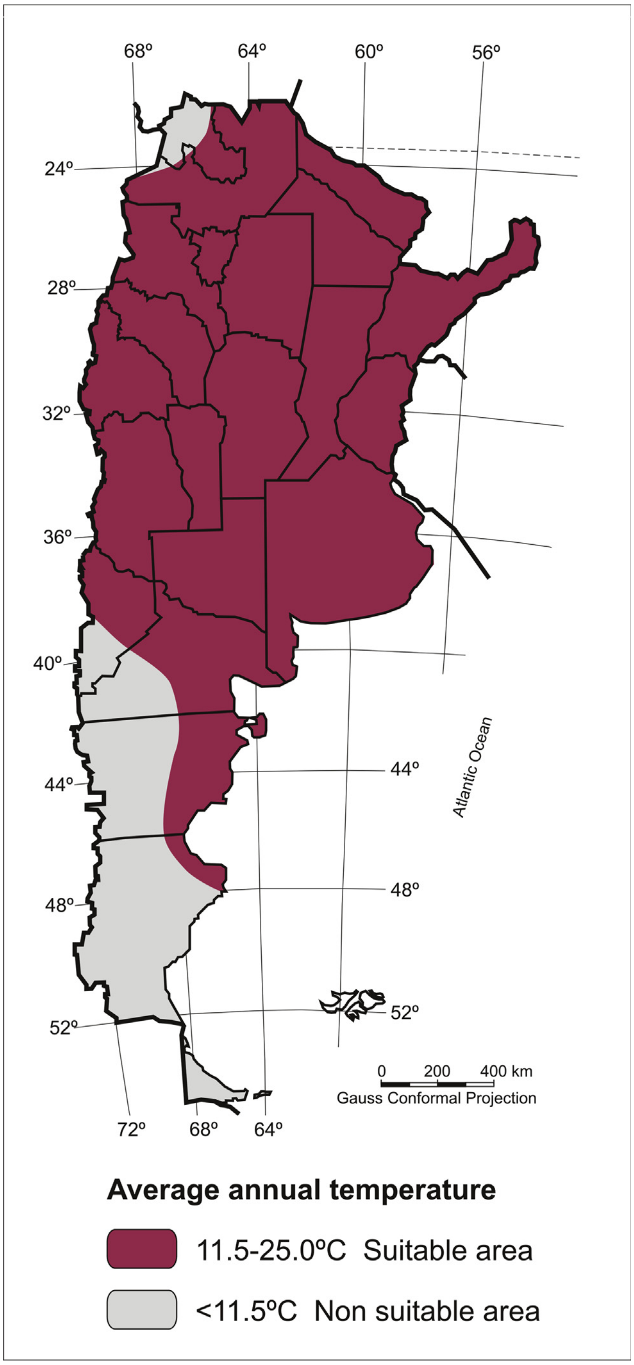

Fig. 5 – Average annual temperature.

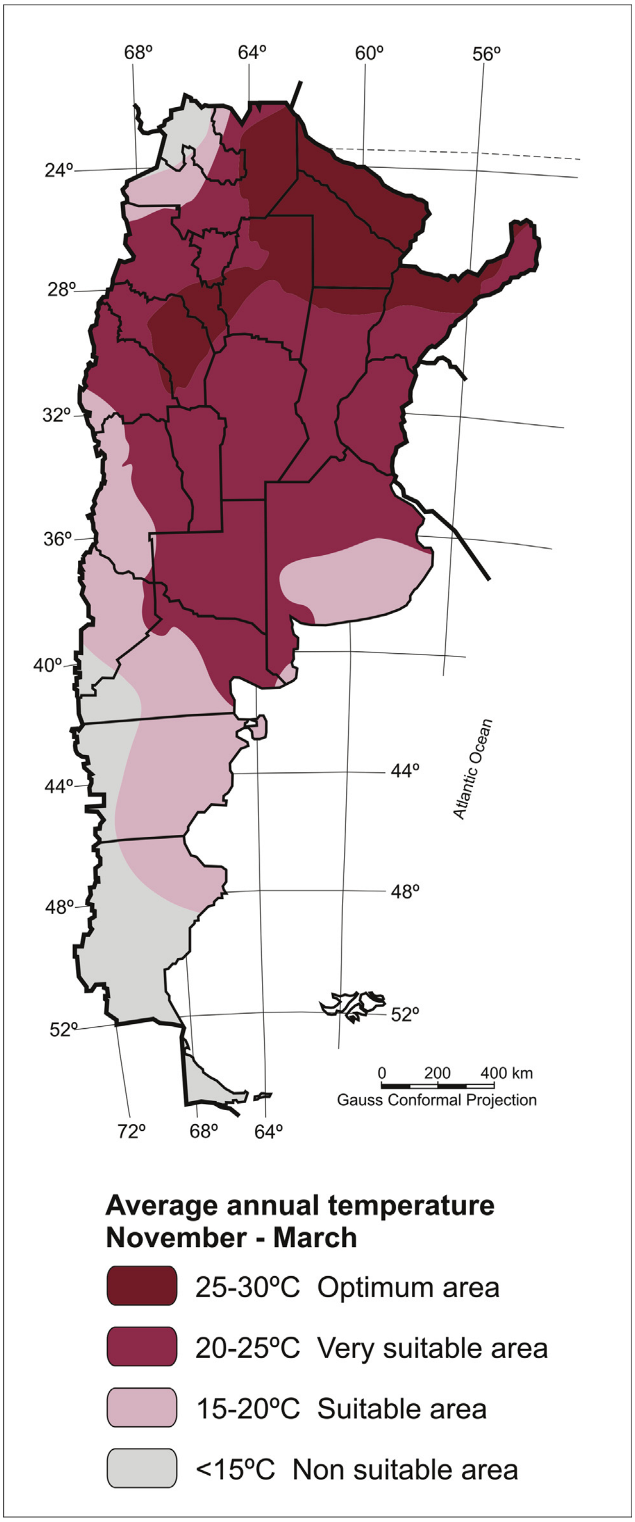

Fig. 6 – Average temperature during the growing period (November–March).

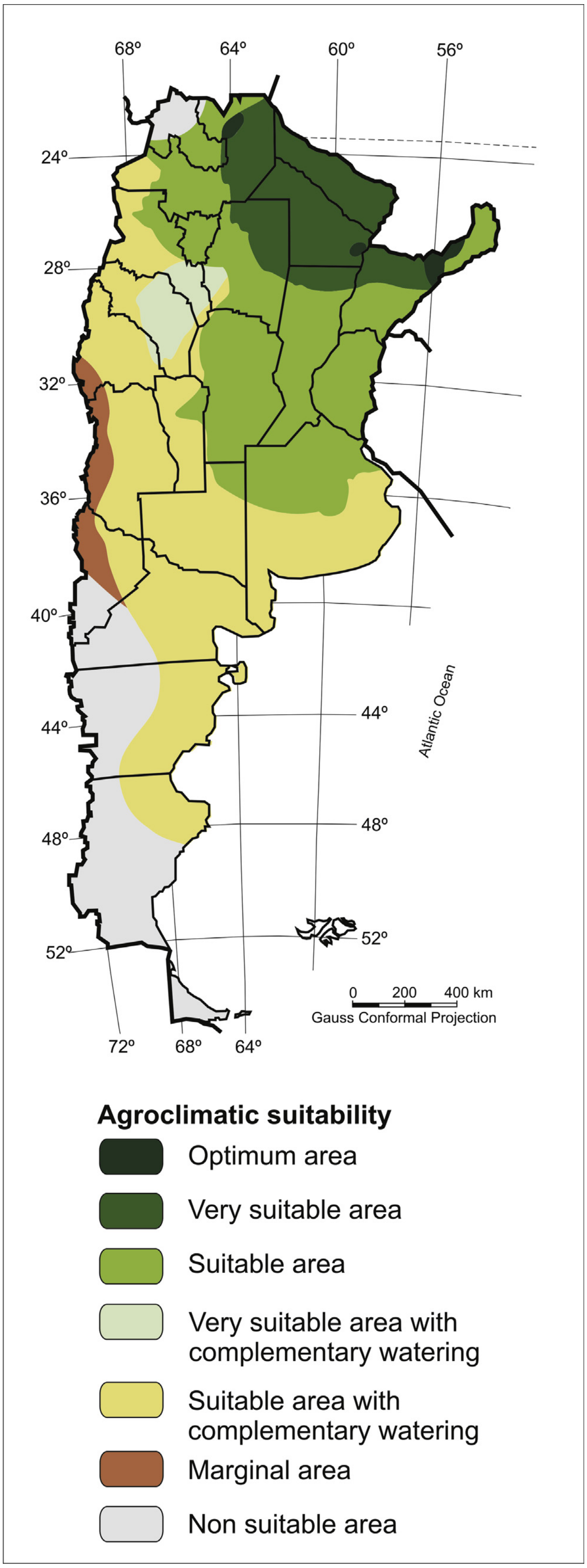

Fig. 7 – Agroclimatic suitability for kenaf.

considered. The geographic areas that registered temperatures below 11.5 °C were qualified as non-suitable.

Finally, the average temperatures during the growing period were analyzed. When these temperatures were lower than 15 °C, the area was deemed non suitable, while in the15 °C to 20 °C range it was suitable, very suitable from 20 °C to 25 °C and optimal from 25 °C to 27 °C.

To obtain the maps, a series of previously interpolated bioclimatic variables were used. Afterwards, these were processed with the Geographic Information System (GIS) tool of the Arc-GIS 9.3 Program. The bioclimatic variables were obtained from their interpolation from 125 meteorological stations of the National Meteorology Service, which cover all the Argentine Republic. Climatic interpolations were made using the "Interpolate to Raster" tool, within the "3D Analyst" extension of the same program, following the Ordinary Kriging interpolation method.

The four maps described above were superimposed to determine the agro-climatic zoning. With the available database, the geographical limits for the different variables were used to define and map aptitude classes. As a result, seven classes of agroclimatic suitability areas were classified as optimal, very suitable, very suitable with complementary irrigation, suitable with complementary irrigation, suitable, marginal and non suitable.

Optimal areas were those where the frost free days >150, the average annual temperature >11.5 °C, the average temperature of the growing period ranged from 25 to 27 °C and the average rainfall of the growing period ranged from 780 to 1200 mm.

Very suitable areas had frost-free days >150, the average annual temperature >11.5 °C, the average temperature of the growing period ranged from 20 to 25 °C and the rainfall of the growing period ranged from 500 to 780 mm.

Very suitable areas with complementary irrigation had frost-free days >150, the average annual temperature >11.5 °C, the average temperature of the growing period ranged from 20 to 25 °C and the annual rainfall of the growing period was <500 mm.

Suitable areas had frost-free days >150, the average annual temperature >11.5 °C, the average temperature of the growing period ranged from 15 to 20 °C and the rainfall of the growing period ranged from 500 to 780 mm.

Suitable areas with complementary irrigation had frost-free days >150, the average annual temperature >11.5 °C, the average temperature of the growing period ranged from 15 to 20 °C and the rainfall of the growing period was <500 mm.

Marginal areas, however, had frost-free days <150 days, average annual temperatures >11.5 °C, the average temperature of the growing period was 15 to 20 °C and the rainfall of the growing period was <500 mm.

Finally, non-suitable areas were those which combined 2 or more of the following variables: frost-free days <150 days, average annual temperature <11.5 °C, average temperature of the growing period <15 °C or the rainfall of the growing period <500 mm.

Furthermore, the map outlined by Ref. [33] to delineate the arid, semiarid, sub-humid and humid areas in Argentina using Thornthwaite's Moisture Index (TMI) was employed. The

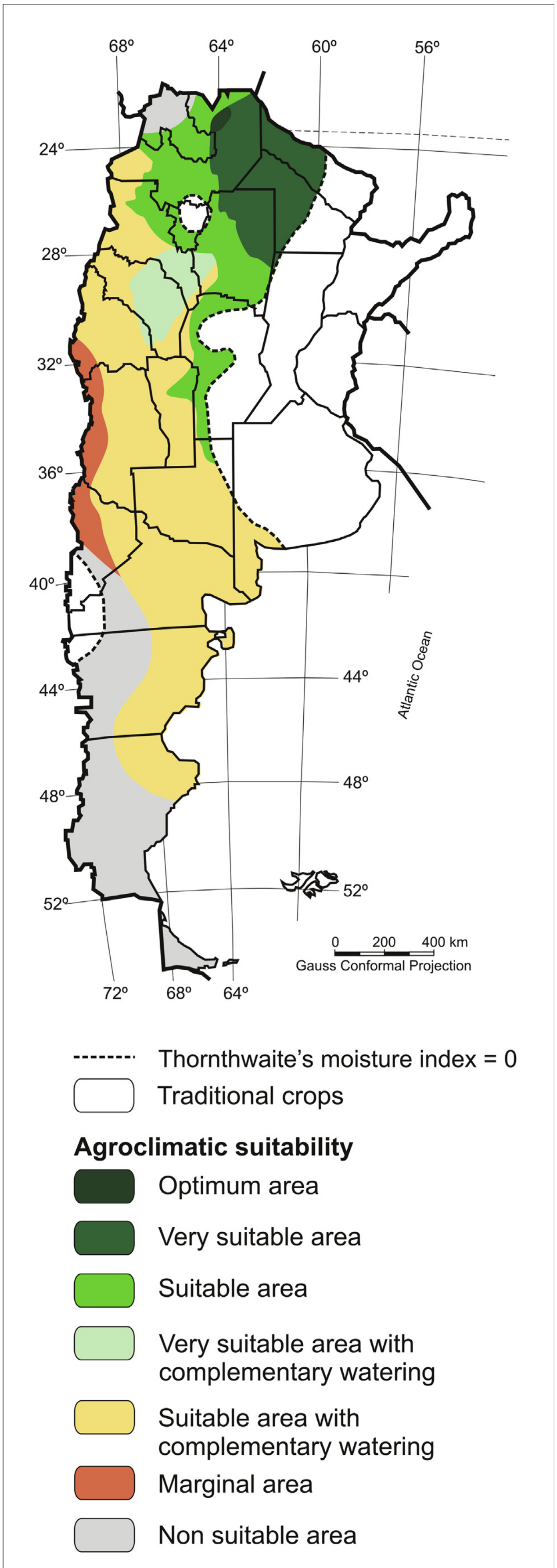

Fig. 8 – Agroclimatic suitability for kenaf under dry-subhumid, semiarid and arid climates.

regions that lie outside of the limit traced by a TMI = 0 have dry-subhumid, semiarid and arid climates. By using this index, the territory in Argentina that is suitable for traditional agriculture is excluded, thus guaranteeing that the lands to be occupied by the proposed energy crop are located under dry-subhumid, semiarid or arid climate conditions.

Also, based on the Argentinean soils map [34], soils that are not suitable for traditional agriculture (under dry-subhumid, semiarid and arid climate conditions) were targeted as possible implantation sites for kenaf. This map and the agroclimatic suitability map under dry-subhumid, semiarid and arid climate, described in the previous paragraph, were then superimposed and the overlapping regions defined the agro-ecological zoning.

Agroclimatic suitability and agro-ecological suitability mapped variables were obtained from multivariable integration geo-processing, using the “Raster Calculator” tool of the “Spatial Analyst” extension of the same program described above.

3. Results and discussion

Fig. 1 shows Argentina's localization in the World map. In order to identify the areas classified with different grades of agroclimatic and agro-ecological fitness, Argentina's political map, with the names of the provinces, is shown in Fig. 2.

Fig. 3 shows the areas where 150 frost-free days are available. These include a large part of the national territory, and it is during this period that agricultural activities can be implemented. In this case, it also represents the duration of the kenaf growing period.

Fig. 4 shows the average rainfalls during the growing period (November–March). There are 5 distinct optimal areas that comprise: the entire province of Misiones, a part of Corrientes that borders with Misiones and small areas in the provinces of Salta, Jujuy, Chaco and Tucumán. A large part of the Chaco-Pampean plain, reaching the province of Buenos Aires, is suitable from a hydric perspective.

In Fig. 5, the suitable area with an average annual temperature equal or higher than 11.5 °C can be observed. If the temperatures are lower, the culture's growth decreases. The suitable area located in Argentina presents average annual temperatures ranging from 11.5 to 25 °C.

The areas with different ranges of mean temperatures during the growing period of kenaf, which extends from November to March, are shown in Fig. 6. The optimal areas, from a thermal point of view, are located to the north, northeast and center of the country, covering part of the province of Misiones, north of Corrientes, the entire provinces of Chaco and Formosa, part of Salta and Jujuy, a large portion of Santiago del Estero, the north of Santa Fe and part of San Juan, La Rioja, Catamarca and Tucumán. However, the areas classified as very suitable circumscribe the optimal ones, extending toward the South, West and East. They comprise the north and center of the country, and they reach the

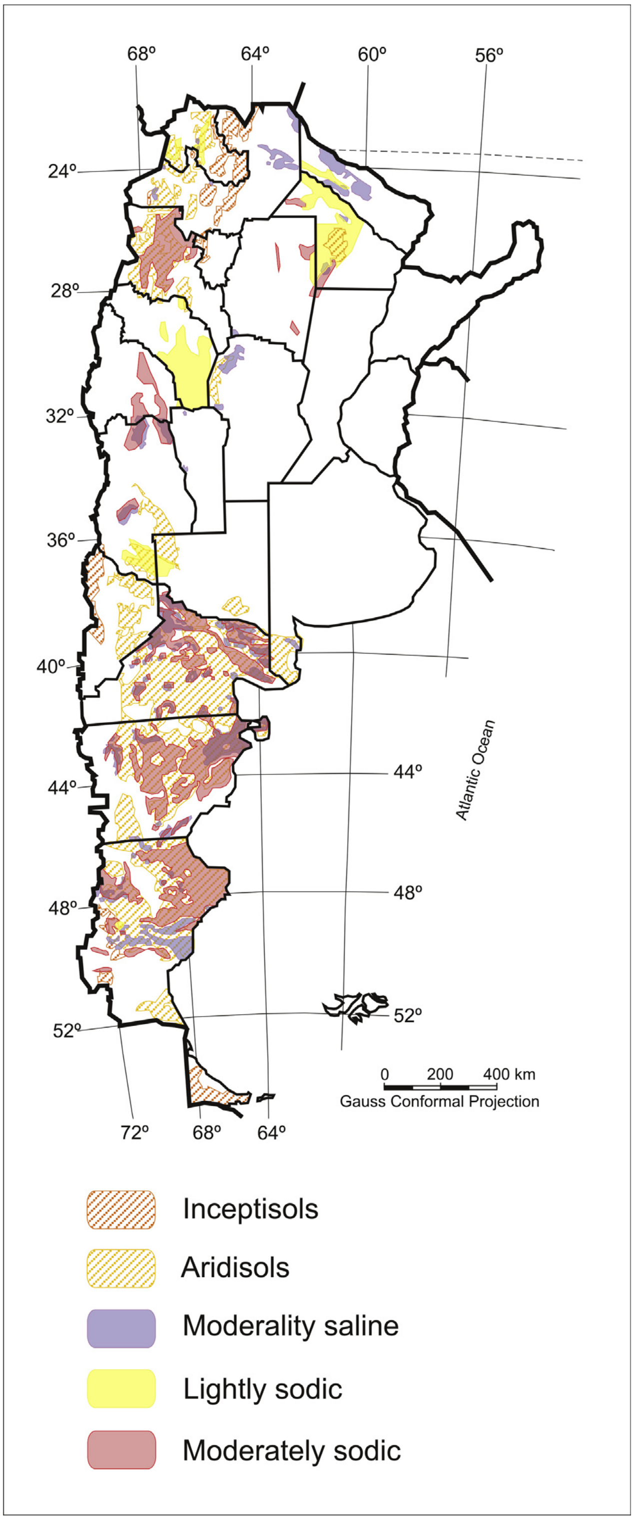

Fig. 9 – Non suitable soils for traditional crops under dry-subhumid, semiarid and arid climate conditions.

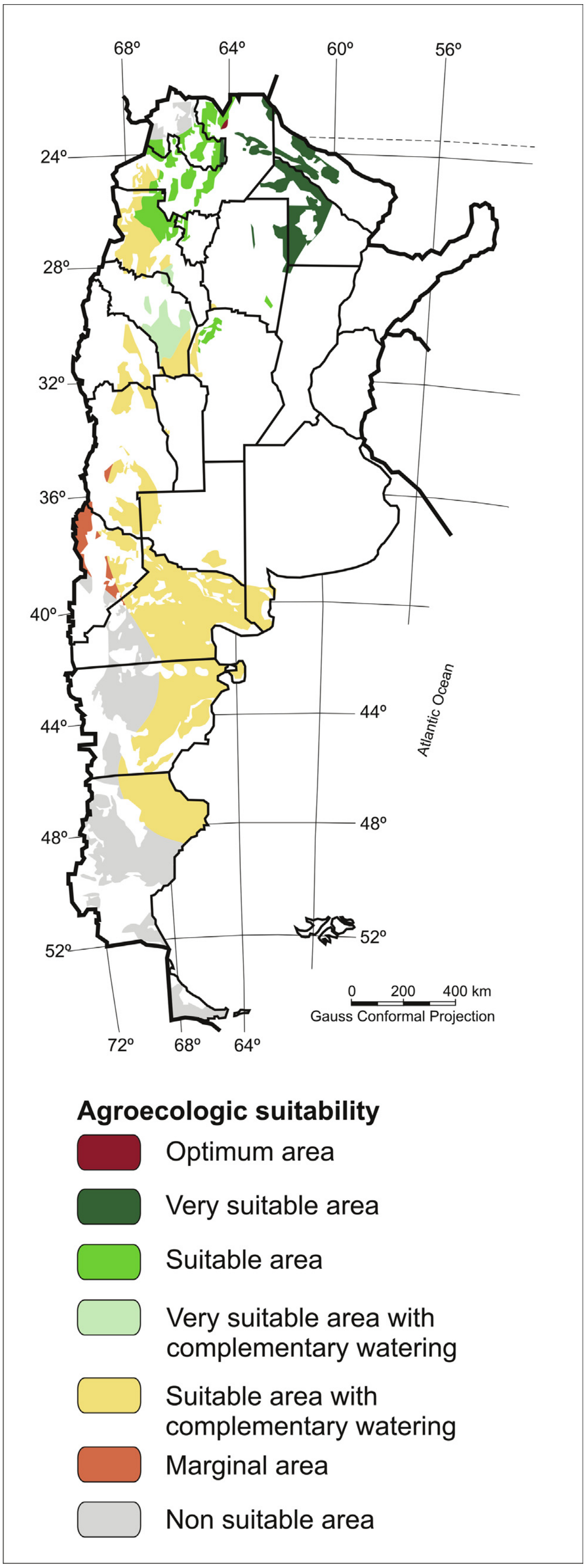

Fig. 10 – Agro-ecological zoning for kenaf.

province of San Juan, Mendoza, Rio Negro and the east of Neuquén and the center and the south of Buenos Aires. The suitable areas include the center and the south of Buenos Aires, NW and west of Argentina, and extend to the province of Santa Cruz, in the Patagonia.

Fig. 7, which emerged from the superimposition of the 4 previous figures, represents the agroclimatic zoning for kenaf for the production of fiber, forage and biomass.

In the agroclimatic zoning shown in Fig. 7, seven classes of fitness were differentiated. The optimal areas cover the north of Corrientes, part of Misiones, the west of Chaco and the north of Salta. Very suitable areas cover a large portion of the north of our country, including the entire provinces of Chaco and Formosa, east of Salta, northwest of Santiago del Estero, north of Santa Fe and part of Corrientes. The suitable areas comprise part of the province of Misiones, a great part of the Northwest of Argentina and a great part of the Pampean plain, reaching the center of the province of Buenos Aires. An area that occupies part of the provinces of La Rioja, Catamarca, San Juan and Santiago del Estero appears as very suitable with complementary watering. Toward the South and the West, there is an area suitable with complementary watering that extends from the Northwest of the country and reaches the province of Santa Cruz, in the Patagonian Region. Marginal areas cover the west of San Juan, Mendoza and Neuquén.

Fig. 8 shows the Agroclimatic suitability map under dry-subhumid, semiarid and arid climates delimited by the Thornthwaite's Moisture Index = 0.

Fig. 9 shows non suitable soils for traditional crops. These correspond to the Aridisols and Inceptisols (Soil Orders from the US Soil Taxonomy), as well as soils with problems of salinity and alkalinity. Considering kenaf's tolerance to salinity and alkalinity, the appropriate soil phases for its cultivation would be the light and moderately saline (whose electrical conductivity ranges from 4 to 8 dS m^{-1}) and moderately alkaline ones (whose exchangeable sodium percentage ranges from 2 to 40%).

Finally, Fig. 10 shows the agro-ecological suitability map for kenaf in soils unsuitable for traditional agriculture. The optimal area occupies a reduced sector in the province of Salta. At this moment, cultivation of kenaf for the production of fiber is being tested in this particular region. Very suitable areas cover part of the provinces of Formosa, Salta, Chaco, Santiago del Estero and Jujuy. Suitable areas are located in Salta, Jujuy, Cordoba, Santiago del Estero, Catamarca and Tucumán. Very suitable areas with complementary watering are found in the provinces of La Rioja and Catamarca. Suitable areas with complementary watering cover large extensions to the west of Argentina and in the Patagonian region. Marginal areas are detected only in the provinces of Neuquén and Mendoza.

If the final objective of the kenaf crop is to obtain fiber or forage, the production costs and the market prices must be considered to decide if the cost of complementary irrigation is justified. However, if kenaf is going to be destined to produce lignocellulosic material, with thermal purposes or to produce second generation biofuels, the use of complementary irrigation is definitely not recommended.

The implantation of kenaf with irrigation in the Patagonia region is not recommendable due to a variety of factors. Although it has warm summers (28 °C–32 °C, but with relatively cool nights at 15 °C), the number of frost-free days is scarce and, consequently, the possible growing periods are too short. Furthermore, the region is characteristically arid and the Relative Humidity during the year is very low. The strong west winds are persistent during the year and their high intensity produce an increase in the atmospheric demand (evapotranspiration), with the concomitant permanent demand of water for irrigation.

Geographically, the location for kenaf implantation starts at 35°L and continues toward the North, resulting in longer growing periods and increased production of lignocellulosic material. This is possible in the areas classified as optimal, very suitable and suitable, presented in Fig. 10.

4. Conclusion

This work demonstrates that a large extension of Argentina possesses agro-ecological suitability for kenaf under dry-subhumid and semiarid climates and rainfed conditions. Furthermore, the soils proposed for the implantation of this energy crop are unsuitable for traditional agriculture, thus avoiding the biofuels versus food controversy.

When the environmental requirements and the potential for forage cultivation are taken into account, kenaf appears as an alternative crop that can be integrated into the farming production in the dry-subhumid and semi-arid regions of Argentina. The main advantage of kenaf is that it has one of the highest yields of biomass per hectare. Consequently, it can generate new business opportunities in the rural areas of Argentina, promoting diversity in the agriculture matrix and, at the same time, generating innovative materials for different industries. Kenaf can be used as a source of fiber, forage and biomass, either independently or simultaneously. For example, the leaves in the superior part of the kenaf plant are not appropriate for the production of paper pulp, but they could be used as forage or as biomass residue.

Finally, the value of this model of agro-ecological zoning is not merely local, since it can be applied to any part of the world using the same agroclimatic limits presented in this paper.

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