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Different scenarios in land suitability assessment for Kernza®-intermediate wheatgrass (*Thinopyrum intermedium*), a novel perennial grain crop for Argentina

Diferentes escenarios para evaluación de la aptitud de la tierra para Kernza®-intermediate wheatgrass (*Thinopyrum intermedium*), un nuevo cultivo de granos perenne para Argentina

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Abstract

Land degradation, climate change, soil and water contamination have led to increased interest in sustainable agricultural practices. Most agricultural practices are focused on growing annual crops, which require significant amounts of synthetic fertilizers, contribute to CO_2 emissions and disrupt natural biological processes. Natural Systems Agriculture has been developed to reverse this paradigm by imitating nature through perennial grain crops. Kernza® intermediate wheatgrass *(Thinopyrum intermedium)* is a promising perennial crop producing healthy grain for direct human consumption and forage for livestock while providing multiple ecosystemic services. Given these reasons, consider its cultivation in Argentina is relevant. This research aimed to predict Kernza crop suitability in the Azul district by modeling different climatic and soil densification scenarios. The model showed that Kernza can be grown in Azul, and that southern areas were most suitable. This model allowed generating information for land use planners and farmers to consider planting in Argentina, particularly, in Azul.

Keywords
land evaluation • climate scenarios • land degradation • perennial crops

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RESUMEN

La degradación del suelo, el cambio climático y la contaminación del suelo y el agua han suscitado un mayor interés por una agricultura más sostenible. La mayoría de las prácticas agrícolas se centran en cultivos anuales, que requieren grandes cantidades de fertilizantes sintéticos, contribuyen a un aumento en las emisiones de CO_2 y perturban los procesos biológicos naturales. El "Natural Systems Agriculture" se ha desarrollado con el objetivo de revertir este paradigma mediante la imitación de la naturaleza a través de cultivos de granos perennes. El Kernza® intermediate wheatgrass *(Thinopyrum intermedium)* es un cultivo perenne muy prometedor porque produce grano para consumo humano, forraje para el ganado y proporciona múltiples servicios ecosistémicos. Por ello, es relevante considerar su cultivo en Argentina. El objetivo fue predecir la aptitud de Kernza mediante la modelización de diferentes escenarios climáticos y de densificación del suelo en el partido de Azul, Argentina. El modelo demostró que el Kernza puede ser cultivado en Azul, siendo las zonas del sur las más aptas. El Kernza es un cultivo muy prometedor y este modelo permitió generar información para que los planificadores del uso de la tierra y los agricultores consideren su plantación en Azul, y en Argentina.

Palabras claves
evaluación de tierras • escenarios climáticos • degradación de tierras • cultivos de granos perennes

INTRODUCTION

Land degradation, climate change, soil and water contamination have led to increased interest in sustainable agricultural practices (4, 23, 35, 54). Despite this, most agricultural practices are still focused on growing annual crops, which require significant amounts of synthetic fertilizers, labour, contribute to emissions of CO_2 and disrupt natural biological processes (2, 10). This reduces the current and potential capacity to produce goods and services, both qualitatively and quantitatively (19, 20, 21). Additionally, this causes an increase in the energy necessary to produce environmental and economic liabilities (56). In 1980, Wes Jackson published the book New Roots for Agriculture (32) to reverse this paradigm, developing the concept of Natural Systems Agriculture (NSA). In this perennial food-grain-producing system, soil erosion and agrochemical contamination decrease as fossil fuel dependency decreases (33). Its objective was to mimic nature using perennial grain crops. Unlike annuals, perennials improve soil structure and water retention capacity, contribute to climate change adaptation and mitigation, and promote biodiversity and ecosystemic functions (2, 12, 25). Additionally, they improve rural economies by reducing external inputs (*i. e.*, reducing dependence on fossil fuels and agrochemicals) and labour intensity (11, 12, 44).

Kernza® is the trade name of the intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth and D.R. Dewey], a novel perennial grain crop recently becoming commercially available in the USA (15, 41). Kernza´s deep root system reduces nutrient leaching while increasing water use efficiency and soil carbon content (10, 14, 25). In addition, Kernza provides a grain suitable for direct human consumption, forage for livestock, and multiple ecosystemic services for enhanced environmental quality (12, 24, 28, 49, 52).

Territory is used for different purposes, occasionally complementary but mostly conflicting (*i.e.*, they cannot be located simultaneously in the same area). For these reasons, land-use planning plays a major role in considering exploitation of natural resources; assessing requirements and land capacity, identifying and resolving conflicts among competing uses and seeking long-term sustainable solutions (19, 20, 31). Land evaluation assesses land suitability for specific purposes, constituting an integral part of land-use planning, providing information for decision-making by land-use planners (19, 20, 40). Land evaluation involves the execution and interpretation of basic studies of climate, soil, vegetation, and any aspect regarding land-use requirements (19). Several methodologies aid the development of land evaluation systems, including modeling, such as expert systems.

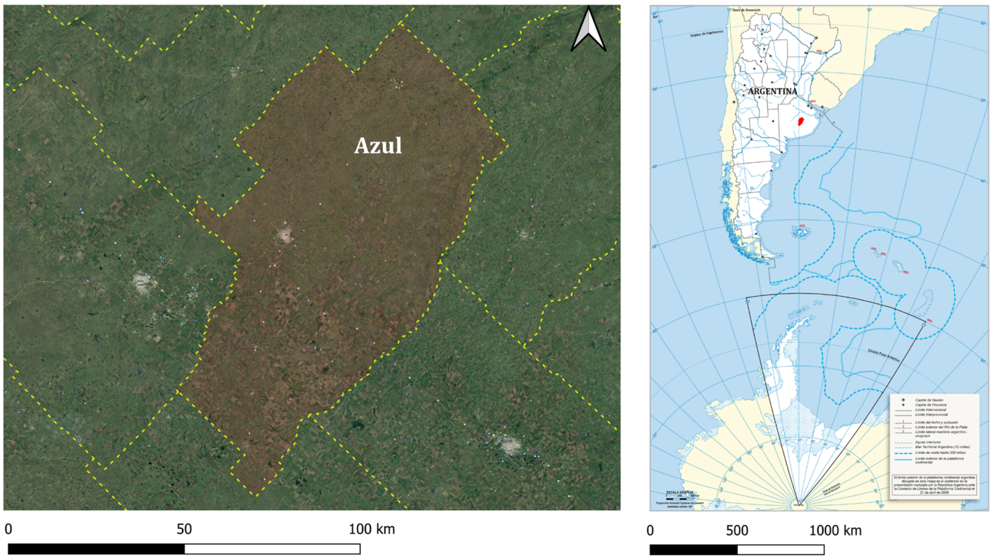
Models allow predicting outcomes under real conditions and generate new hypothetical outcomes in scenarios of change, such as different climate or soil densification scenarios. These hypothetical outcomes facilitate management and adaptation measures to future changes (31, 42, 50, 51).

While perennial grain crops are not widely cultivated worldwide (8, 36) the various agro-ecological benefits they potentially provide make them strong candidates for cultivation in Argentina. This study aimed to predict Kernza crop suitability in Azul district by modelling different climatic and soil densification scenarios in Azul district, Argentina.

MATERIALS AND METHODS

Study area

Azul district is located in the centre of Buenos Aires province, Argentina (36°14' S - 37°27' S and 59°8' W - 60°10' W) in the Pampa region, with an area of 6,551 km^2 (figure 1) and 70 545 inhabitants. It is divided into two large areas: southern Pampa in the south and flooding Pampa in the north (46).



(Landsat/Copernicus image. ©Google, 2022).

Figure 1. Location of Azul district in Argentina.

Figura 1. Ubicación del partido de Azul en la Argentina.

According to the Köppen classification (34), Azul has a humid temperate climate (Cfb) with oceanic influence, hot summers, and precipitations evenly distributed throughout the year (7, 43, 53). Mean annual rainfall is 921 mm (1931-2017 series). Minimum annual rainfall recorded in 1935 was 590 mm, and maximum annual rainfall in 2012 was 1449 mm. In addition, different precipitation periodicities were observed in intervals of 12 and 2.5 years (6, 53). Azul mean annual temperature is 14, 2°C (1997-2018 series). January is the hottest month with an average temperature of 21, 8°C, while August is the coldest with an average of 7 °C. Mean annual potential evapotranspiration is 752 mm. December, January and February present the higher atmospheric demand.

Soils are Argiudolls, Hapludolls, Natraquolls and Natraqualfs (30, 46, 47). Land uses are agriculture, livestock, and crop-livestock systems (57). Soybean (*Glycine max*), corn (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and sunflower (*Helianthus annuus*) are the major crops. Livestock plays an important role in the district, especially in the Pampa Deprimida area (39).

Kernza crop suitability modelling

The ALES (Automated Land Evaluation System) v4.65e software (50, 51) was modelled under the FAO Land Evaluation Framework (19, 20, 21). Model inputs were Kernza requirements (table 1), soil characteristics (table 2, page 52-53), and climate characteristics (table 3, page 53). Suitability was determined by comparing Kernza crop requirements with land qualities (table 4, page 54) selected through decision trees (Supplemental data 2). The model was based on Kernza land utilization involving grain and forage production without irrigation for four years. Farming techniques include direct drilling, fertilization with nitrogen and phosphorous, phytosanitary applications and mechanized harvesting. The crop is seeded in March, with grain harvesting in January, followed by two forage harvests, one after grain harvest and another in April or May.

Table 1. Kernza land use requirements.

Tabla 1. Requerimientos del uso de la tierra para Kernza.

Requirements	Kernza	References
Seeding date	March	(41)
	May	(Locatelli, 2020*)
Vernalisation	Yes	(37, 41)
Soil moisture retention	Coarse textured soils with low water retention capacity particularly in areas with abundant rainfall, given root exploration capacity	(41)
PET, reproductive period	328 mm (October to January)	(16)
PET, vegetative period	349 mm (February to September)	(16)
Seeding density	11 a 13 kg·ha^{-1} of seeds	(16)
	16.81 kg·ha^{-1} of seeds	(45)
	13 kg·ha^{-1} or 130 seeds·m^{2} at 0.15 m away or 19.7 seeds·m^{-1} 36 seeds·m^{-2} to 145 seeds·m^{-2}	(14, 16, 22)
	Achieve a stand of 20 live plants·m^{-2}	(Locatelli, 2020*)
Seeding deep	1.2 to 2.5 cm	(16)
Row spacing	75 cm	(16)
	15 cm	(14)
	ñ30 cm to 60 cm	(28)
Fertilization	Nitrogen: 110 kg·ha^{-1} before seeding (1st year), 100 kg·ha^{-1} (2nd year), 90 kg·ha^{-1} (3rd year) then decreasing to 80 kg·ha^{-1} (4th year); Phosphorus: before seeding 10 to 20 ppm	(16)
	Nitrogen: Applied the first year during seeding 36 kg·ha^{-1}. Post-harvest and early spring 36 kg·ha^{-1}. Phosphorus: in the first year monoammonium phosphate (map, 52% P_2O_5) 67 kg·ha^{-1}	(48)
	Nitrogen: first year at seeding 50 kg·ha^{-1}, then at spring 50 kg·ha^{-1}	(14)
	Phosphorus: monoammonium phosphate (map, 52% P_2O_5) 15 kg·ha^{-1}	(48)

Most references concerning the northern hemisphere have been adapted for the southern hemisphere.

* Andrés Locatelli (Universidad de la República, Uruguay), personal communication, 2020.

La bibliografía consultada corresponde al hemisferio norte y fue adaptada al hemisferio sur.

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Requirements	**Kernza**	**References**
Grain harvest	January, with yield varying from 280.21 kg·ha^{-1} to 1500 kg·ha^{-1}. First-year yields are the highest. Then yields decline until the fourth year when it should be reseeded	(14, 16, 48)
Forage harvest	A mechanical cut 10 cm above the ground is made either once in April or immediately after grain harvest and in April	(48)
Flooding	Does not tolerate excessive moisture	(41)
Crop cycles	It has three stages: early vegetative, from regrowth after harvest until before the onset of colder temperatures (February to April); late vegetative, comprising the period of stem elongation just before flowering (May to September); reproductive stage, from flowering until harvest (November to January)	(48)

Table 2. Selected soil characteristics, classes and ranks.

Tabla 2. Características de los suelos seleccionadas, sus clases y rangos.

Code	**Soil characteristics**	**Classes and ranks**	
Prof_Ef	Soil deep (m)	0.15 - 0.30	Very slight (MuyPocoP)
		0.31 - 0.60	Slight (PocoP)
		0.61 - 0.90	Moderate (ModP)
		0.91 - 1.20	High (P)
		< 1.21	Very high (MuyP)
Agua_Util	Available water (mm/m)	0 - 50	Low (MB)
		50.1 - 75	Moderately low (B)
		75.1 - 100	Moderate (M)
		100.1 - 135	High (A)
		< 135.1	Very high (MA)
Aneg	Water logging	None (N)	
		Moderate (M)	
		High (A)	
		Very high (MA)	
CIC	Cationic exchange capacity (cmol + · Kg^{-1} soil)	0 - 16	Low (B)
		16.1 - 24	Medium (M)
		< 24.1	High (A)
Cond_Elec	Electrical conductivity (dS · m^{-1})	0 - 2	Low (B)
		2.1 - 4	Medium (M)
		4.1 - 6	High (A)
		6.1 - 9	Very high (MA)

Code	Soil characteristics	Classes and ranks	
Dren	Drainage	Very poorly drained (MPD)	
		Poorly drained (PD)	
		Somewhat poorly drained (APD)	
		Moderately well drained (MBD)	
		Well drained (BD)	
		Somewhat excessively drained (AED)	
		Excessively drained (ED)	
OM	Organic matter (%) at topsoil.	0 - 1	Low (B)
		1.1 - 2	Medium (M)
		< 2.1	High (A)
pH	Hydrogen ion concentration	0 - 5.5	Acid (A)
		5.6 - 6	Moderately acid (MA)
		6.1 - 6.5	Slightly acid (LA)
		6.6 - 7.3	Neutral (N)
		7.4 - 7.8	Slightly basic (LB)
		7.9 - 8.3	Moderately basic (MB)
		8.4 - 14	Basic (B)
PSI_Sup	PSI (%) Sodium exchangeable percentage topsoil 0 - 0.20 m	0 - 5	Low (B)
		5.1 - 10	Medium (M)
		10.1 - 15	High (A)
		< 15.1	Very high (MA)
PSI_SubS	PSI (%) Sodium exchangeable percentage subsoil 0.21 - 0.50 m	0 - 5	Low (B)
		5.1 - 10	Medium (M)
		10.1 - 15	High (A)
		< 15.1	Very high (MA)

Table 3. Climate characteristics selected, classes and ranks.
Tabla 3. Características del clima seleccionadas, sus clases y rangos.

Code	Climate characteristics	Classes and ranks	
PP_Repro	Precipitation in the reproductive period (mm)	50 - 150	Extremely low (MB)
		151 - 250	Low (B)
		251 - 350	Medium (M)
		351 - 500	High (A)
		> 501	Very high (A)
PP_ Vegeta	Precipitation in the vegetative period (mm)	100 - 250	Extremely low (MB)
		251 - 300	Low (B)
		301 - 350	Medium (M)
		351 - 500	High (A)
		> 501	Very high (A)

Table 4. Simulation of different precipitation scenarios. Different precipitation probabilities are observed for each period and each soil densification.

Tabla 4. Simulación de los diferentes escenarios de precipitación para las diferentes probabilidades de ocurrencia en cada periodo del cultivo y densificación del suelo.

Probability	Precipitation (mm)	Precipitation (mm)	Precipitation (mm)	Soil densification
	Reproductive period	Vegetative period	Annual	
20%	186	215	401	Minimum
50%	368	554	922	Minimum
80%	548	889	1437	Minimum
20%	149	172	321	Maximum
50%	294	443	737	Maximum
80%	438	711	1149	Maximum

Kernza crop requirements

Edaphoclimatic characteristics (table 2, page 52-53 and table 3, page 53) were selected, and different classes and ranks were defined (Locatelli 2020*, 2, 9, 14, 16, 22, 28, 36, 41, 48). Soil data were obtained from soil profiles of the 1:50000 soil maps (13, 30). Climate data were obtained from the climate analysis by Cassani (2020) and SMN (2018).

Available water content up to 1 meter was indirectly obtained with the Travasso & Suero model (1994), developed and validated for the southern Pampa region.

Decision trees were assembled according to edaphoclimatic characteristics and logical criteria based on expert knowledge determining land qualities (31, 40, 42). Seven land qualities were determined for model development (Supplemental data 2): Oxygen availability (Disp_O), Root depth (Exp_Rad), Nutrient availability (Disp_Nut), Exchangeable sodium percentage (%PSI), Water logging (Aneg) and Available water (Disp_Agua). Land qualities were assessed using four classes according to the FAO framework (1976, 1985, 2007), from the lowest (1) to the highest level of use limitation (4).

Climate and soil densification scenarios

Scenarios were proposed according to cumulative probabilities of precipitation for P20%, P50% and P80% (table 4). These scenarios were calculated with data obtained from Cassani (2020) and the SMN (2018).

Considering that past or current land use can affect planning and change crop suitability, scenarios of maximum and minimum soil densification were simulated for each cumulative precipitation setting. As physical degradation is the major soil degradation in Argentina (1, 5, 58), a theoretical maximum bulk density was calculated according to Duval *et al.* (2015) equation [1] as maximum soil densification. Minimum soil densification was determined as a bulk density of 1.2 g/cm^3 (47) (Supplemental data 1), simulating the occurrence of soil densifications, which decrease rainfall infiltration and percolation. On average, this led to a 20% reduction in water availability, generating different starting points for the Kernza suitability model for available water (table 4). Thus, lands with high soil densification are physically degraded, so the available water is lower. Also, in case of excess precipitation, drainage capacity is limited.

$$\textit{Maximun bulk density } (g \, . \, cm^{-3}) = 1.766 - 0.00598 \, _{*} (\%silt) - 0.0158 \, _{*} (\% \textit{ Organic Carbon}) \quad (1)$$

Kernza suitability assessment was conducted by comparing Kernza requirements *vs.* land qualities. Kernza suitability was evaluated by considering the maximum limitation method (31) for each decision tree created (Supplemental data 2). We have expanded the four FAO categories into nine subcategories (figure 2, page 52-53; table 5, page 56) indicating suitability of each soil map unit. The assessment focuses on identifying potential limitations and risks associated with the different scenarios. In the maximum soil densification scenario, current unsuitable land can be reverted and turned into suitable land. This is not the case for permanently unsuitable land (figure 2, table 6, page 56). Results were mapped using QGIS v3.10.8-A Coruña (49).

Soil map units identified in the 1:50000 maps (13, 30) were used as land units for this study. A total of 134 mapping units were identified, composed of 90 soil series and their phases (Supplemental data 1).

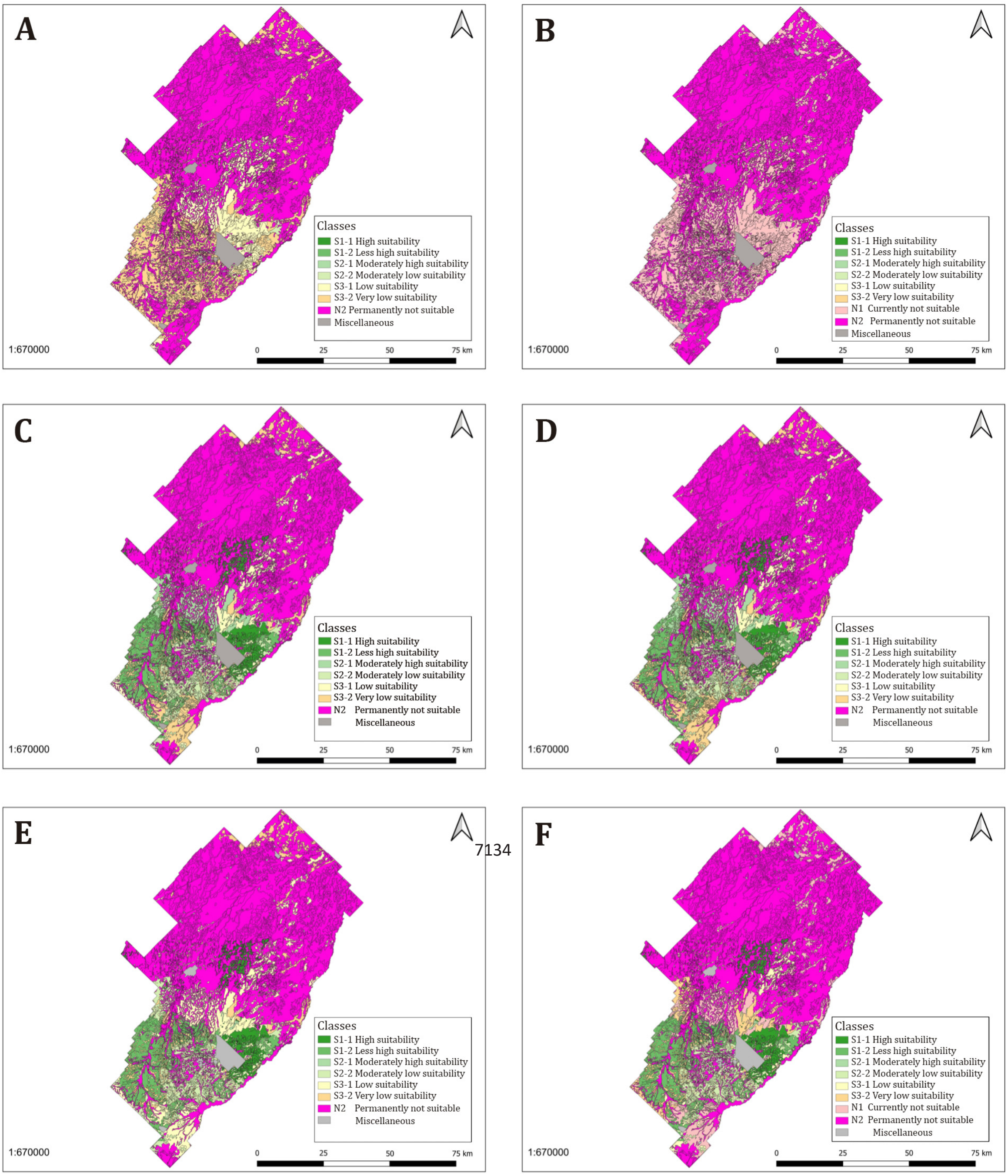

Figure 2. Land suitability for Kernza in minimum soil densification scenario for P20% (A), P50% (C) and P80% (E) scenarios, and in maximum soil densification scenario for P20% (B), P50% (D) and P80% (F).

Figura 2. Aptitud de la tierra para Kernza en el escenario de mínima densificación del suelo para los escenarios P20% (A), P50% (C) y P80% (E), y para el escenario de máxima densificación del suelo para los escenarios P20% (B), P50% (D) y P80% (F).

Table 5. Occupied land suitability for Kernza in minimum soil densification scenario for P20% (A), P50% (C) and P80% (E) climate scenarios (km^2).

Table 5. Superficie ocupada por las distintas aptitudes para Kernza en el escenario de mínima densificación del suelo y P20% (A), P50% (C) y P80% (E) (km^2).

P20%		P50%		P80%	
Class	**Km^2**	**Class**	**Km^2**	**Class**	**Km^2**
High Suitability	0	High Suitability	238	High Suitability	238
Less High Suitability	0	Less High Suitability	508	Less High Suitability	495
Moderately High Suitability	0	Moderately High Suitability	236	Moderately High Suitability	5
Moderately Low Suitability	13	Moderately Low Suitability	410	Moderately Low Suitability	430
Low Suitability	652	Low Suitability	347	Low Suitability	702
Very Low Suitability	1170	Very Low Suitability	457	Very Low Suitability	294
Unsuitable	4566	Unsuitable	4205	Unsuitable	4237
Miscellaneous	150	Miscellaneous	150	Miscellaneous	150
Total	6551	Total	6551	Total	6551

Table 6. Occupied land suitability for Kernza in maximum soil densification scenario for P20% (B), P50% (D) and P80% (F) climate scenarios in Km^2.

Table 6. Superficie ocupada por las distintas aptitudes para Kernza en el escenario de máxima densificación del suelo y P20% (B), P50% (D) y P80% (F) en Km^2.

P20%		P50%		P80%	
Class	**Km^2**	**Class**	**Km^2**	**Class**	**Km^2**
High Suitability	0	High Suitability	209	High Suitability	238
Less High Suitability	0	Less High Suitability	481	Less High Suitability	495
Moderately High Suitability	0	Moderately High Suitability	290	Moderately High Suitability	5
Moderately Low Suitability	0	Moderately Low Suitability	411	Moderately Low Suitability	320
Low Suitability	0	Low Suitability	268	Low Suitability	209
Very Low Suitability	0	Very Low Suitability	537	Very Low Suitability	287
Currently Unsuitable	1835	Unsuitable	0	Currently unsuitable	610
Permanently unsuitable	4566	Permanently unsuitable	4205	Permanently unsuitable	4237
Miscellaneous	150	Miscellaneous	150	Miscellaneous	150
Total	6551	Total	6551	Total	6551

RESULTS

In the minimum soil densification scenario, most lands in northern Azul were classified as unsuitable considering all precipitation probabilities. By contrast, most land in south Azul was classified as suitable in all precipitation probabilities (figure 2A, 2C and 2E, page 55). In P20%, suitable lands were classified under low to very low suitabilities (figure 2A, page 55). On the other hand, in P50% and P80% suitable land was mostly classified under moderately high to very high suitabilities (figure 2C and 2E, page 55). In the P20% scenario, no area was occupied by land with high suitability, less high suitability, and moderately high suitability. A considerably small area was occupied by the moderately low and low suitability classes.

The remaining area was occupied by very low to unsuitable classes (table 5, page 56). In the P50% and P80% scenarios, classes with high and less high suitability occupied a significant area, with equal occupancy in both scenarios. In the P50% scenario, the class with moderately high suitability obtained a high occupation area concerning the P80% scenario, where it was practically insignificant. A shift was observed in the area occupied in the P80% scenario towards the class with low suitability in relation to the P50% scenario. In contrast, the class presenting very low suitability was higher in the P50% scenario than in the P80% scenario (table 5, page 56).

Regarding the maximum soil densification scenario, in P20% all land was classified as unsuitable. Most northern lands were classified as permanently unsuitable. In the south, most of the lands were currently unsuitable (figure 2B, page 55). In P50% and P80%, most northern lands were classified as unsuitable. In contrast, most lands in south Azul were classified as suitable. Suitable lands were classified under very high to moderately low suitabilities. In contrast to P50%, P80% was shown as currently unsuitable land (figure 2D and figure 2F, page 55).

The largest area in the conditionally unsuitable class was in the P20% scenario, followed by the P80%. This first class was not observed in the P50% scenario. In the P50% and P80% scenarios, the highly suitable and less highly suitable classes occupied a significant area, with equal occupancy in both scenarios. In the P50% scenario, the moderately high suitable class obtained a high area of occupation in relation to the P80% scenario, where it was practically insignificant. A shift in the area occupied towards the conditionally unsuitable class was shown in the P80% scenario in relation to the P50% scenario. In contras classes with low to very low suitability were higher in the P50% scenario than in the P80% scenario (table 6, page 56).

Discussion

Precipitation probability strongly influenced results for all scenarios, notably affecting available water. Oxygen availability and exchangeable sodium percentage played a significant role given the very high levels of exchangeable sodium (%PSI) and poor drainage. As a result, most of the land in Azul was unsuitable for Kernza. However, suitable land for Kernza could be found in the Southern region, with favourable cropping conditions. Irigoin (2011) in the Pampa Arenosa region, Argentina, also documented these results, linked to the different climatic scenarios and water availability. In both Pampa Serrana and Pampa Arenosa climate fluctuations related to the ENZO (El Niño Southern Oscillation) phenomenon, are recurrent every 2-3 years (6, 34), making ENZO an important factor in land use planning for Argentina.

Maximun soil densification resulted agreed with Agostini *et al.* (2018) for southern Pampa. Furthermore, the incorporation of the currently unsuitable class was appropriate for the maximum soil densification scenario, allowing the identification of temporarily unsuitable land for Kernza. Soil densification can reversibly modify soil water dynamics, and currently unsuitable land can become suitable for Kernza when densification is removed. In the P20% maximum densification scenario, as water infiltration and percolation were restricted due to densification, annual available water was 321 mm, resulting in all land being classified as unsuitable. A quite different situation was shown in the P20% minimum soil densification scenario with 401 mm, with lands classified as suitable and unsuitable. The maximum soil densification for P80% scenario showed different land classification *vs.* P50%. Suitable lands in P50% became unsuitable in P80%. At higher precipitation, excess water due to soil densification led to higher waterlogging and lower soil oxygen availability. In Azul, suitable areas for Kernza coincide with historical wheat areas (29, 57).

However, according to Law *et al.* (2022) the environmental benefits do have trade-offs with the economic performance of Kernza, as low grain yields would require substantial price premiums to produce net returns equivalent to comparable annual crops. Kernza's current grain yield is relatively low when contrasted with annual wheat, *i.e.*, up to ~1,660 kg ha^{-1} in experimental fields (26, 36), but breeders expect IWG to achieve comparable yields soon (3, 15). The possibility to harvest forage twice a year provides an additional source of income (24, 45). Furthermore, Kernza's deep root system can explore deep soil water, decreasing drought stress (9) due to climate change and the ENZO. Additionally, considering annual crops under fertilization (14) nitrogen leaching decreased while increasing nutrient cycling, and improving fertilizing efficiency, with a consequent reduction in costs. Moreover, bearing in mind that decarbonization is being discussed worldwide (27), carbon sequestration by roots and a lower dependence on fossil fuels for production (12) could position Kernza as the ideal crop. The crop's smaller carbon footprint could be used for carbon credits bringing in additional revenue through inclusion in programs such as the Ecosystem Services Market Consortium (2023). All these ecosystemic services must be considered in the economic equation.

After the recent commercial release of perennial rice in China, shifting from annuals to perennials seems more possible than ever (59). Given all the ecosystemic services provided, Kernza constitutes a very promising crop to consider in the Pampa region, Argentina with temperate climates and wild winters like Uruguay (38). Nextly, Kernza is to be field-tested and promoted among farmers in Azul and the rest of Argentina.

Conclusions

The land suitability model showed that Kernza can be grown in Azul and that southern areas are most suitable. These lands were mostly Argiudolls and Hapludolls, generally deep, with loamy textures, high organic matter content and granular structures in topsoil, and blocky structures in subsoil. They are well to moderately-well drained with high available water. These soil characteristics satisfy Kernza requirements, in concordance with historical wheat areas in Azul.

In addition, the different precipitation scenarios: P20%, P50% and P80%, allowed for determining land suitability. Different precipitation probabilities affect modelled performance of land units by increasing water supply and availability, while different soil densification scenarios modified available water and waterlogging. The maximum suitability expression was in P50% scenario, an average occurrence climatic scenario for both soil densification scenarios.

Given all the ecosystemic services provided, Kernza constitutes a very promising crop for land use planners and farmers in Azul and Argentina.

Supplemmentary material

https://drive.google.com/drive/folders/1O-Sc7NGpM_qOxkAXMoIH49973IwOucP-?usp=sharing

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Data availability statement

The data that support the findings of this work are in supplemental data. Also, openly available in "Zenodo" at https://doi.org/10.5281/zenodo.6884909 and https://doi.org/10.5281/zenodo.6977505.