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PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

Centro Nacional CENAMAD para la Industria de la Madera

The role of forest plantations on soils protection using RUSLE: the case of Chile

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Introduction

Laminar erosion because of agricultural bad practices on ex-native forest soils, Coquimbo Region (f:MPF)

Introduction

1810: Beginning of the Republic

24 Million hectares of forests

1810-1900: High pressure on forest resources

Mining

4-7 millions ha of harvested Forests for copper smelting in Central North Chile (1835-1900)

Agriculture

Wheat exports (California, Australia, England) rises 27 folds its volume (1845-1887)

Cattle raising

Cattle rises 3 folds (1880-1930)

Wood and fuel

Introduction

Serious forests and soil loss, productivity, biodiversity, hydrological systems

Toward 1900 6 million ha forest
were replace with wheat production
(Schneider, 1904)

11 million ha
affected by severe
erosion
(FAO 1979)

16 million ha of
forest lost by 1930
(Haig, 1944)

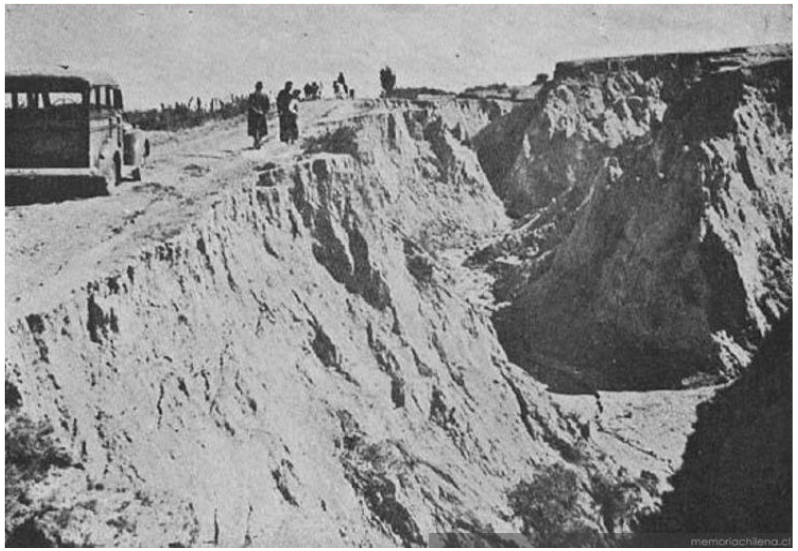
Introduction

The testim...

1856: "…*la espantosa i desoladora corta de nuestros bosques en las provincias centrales i del norte que van agotando todas las fuentes de evaporación al paso que privan a la tierra del abrigo i de la fecundidad de la vejetacion*" (Benjamín Vicuña Mackenna)

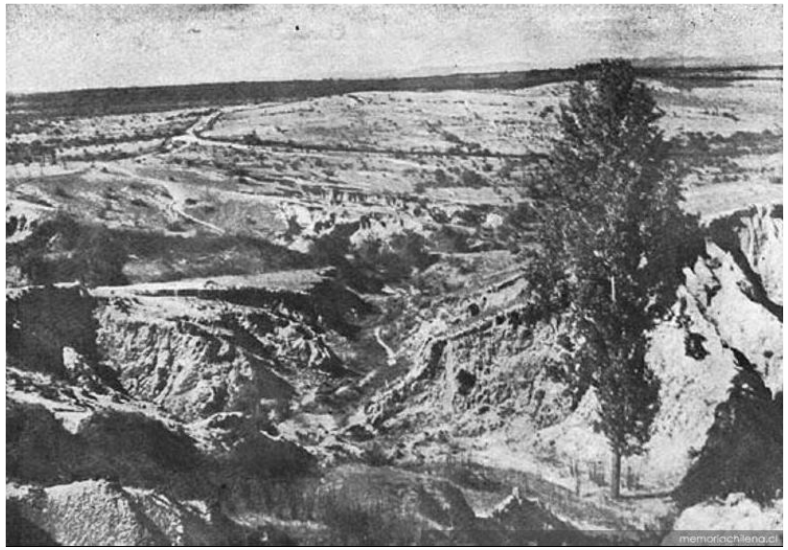
"*Qué cambio ha habido en 10 años entre Temuco y Valdivia! Lloro interiormente al atravesar a sesenta kilómetros por hora la selva virgen de Saco […] cuyo esplendor pasado me maravilla todavía. […] Se ha procedido al roce en todas partes […] es una devastación funesta que hará pronto que la Araucanía antes exuberante, tome el aspecto desnudo y desolado de Chile Central*" (Gustave Verniory, 1889-1899, Victoria, Lautaro y Temuco)

Introduction



V-gully erosion in Cauquenes, 1940

V-gully erosion because of bad agricultural practices during the XXth century

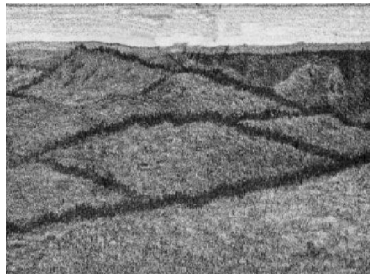


Typical aspect of eroded Chilean soils, 1940

"The hills went nude, being all the vegetal soil destroyed and dragged by the rain, getting dry most of the streams that used to come down their ravines" (Schneider, 1904)

Introduction

Friedrich Albert



Soil protection against erosion

Plantations of the Soc. of Forest Plantations, the Workers Insurance, the "Cía. Carbonífera de Lota" (by Konrad Peters)

Public and private initiatives

First Forest Law D.L. N° 4.363 – 1931

Forest cover recovery

Assays of species introduction and adaptation. Public tree nurseries to encourage plantations by private owners

Future development

First National Forest Reserve in Malleco (1919)

Introduction

Challenges at the beginning of the XX century

- Soil protection and dune control
- Natural resources conservation (creation of protected areas)
- Fast-growing plantations for erosion control and wood production
- Sustainable management of native forests
- Development of the plantation silviculture

- … the rest is history… a strong forestry sector developed over the century

In summary, the Chilean forestry sector was born as a major soil restoration effort!

Objectives

To quantify the potential soil loss (ton ha^{-1} $year^{-1}$) under different covers, soil classes, and rainfall regimes in the south of Chile, to illustrate the contribution of forest plantations to soil protection versus the alternative of maintaining those soils with their historical trajectory of agricultural use or as bare soils.

Material and methods

RUSLE: Revised Universal Soil Loss Equation

$$A = R \times K \times LS \times C \times P$$

Predict the average rate of soil erosion for each feasible alternative combination of crop system and management practices in association with a specified soil type, rainfall pattern, and topography (Wischmeier and Smith, 1978).

With:

A *(ton ha⁻¹year⁻¹)*: **Average soil loss by erosion** in a surface

R *(Mj mm ha⁻¹h⁻¹ year⁻¹)*: Rainfall and runoff factor

K *(ton h ha⁻¹ MJ mm⁻¹)*: Soil erodibility factor

LS *(adimensional)*: Topographic factor (combined slope effect and slope-length effect)

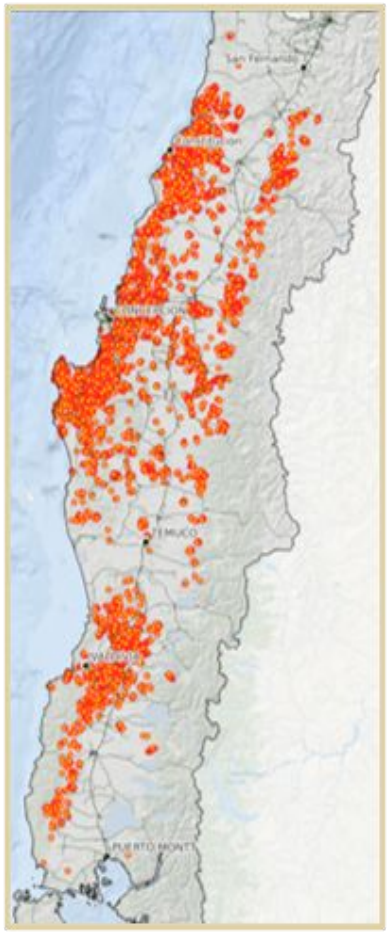
C *(adimensional)*: Cover and management factor

P *(adimensional)*: Support practice factor (not used in this study)

Material and methods

Soil and rainfall data

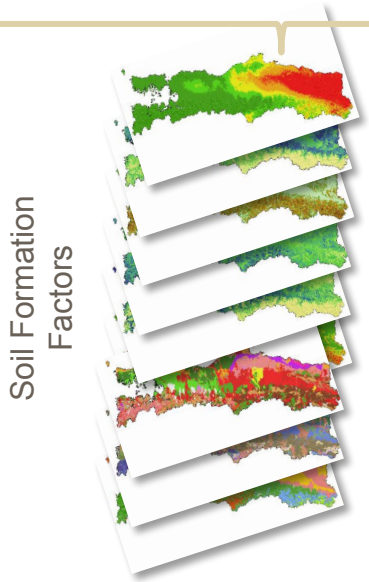
9920 soil test pits
[1991~2018]



Digital soil mapping

$S = f(s.c.o.r.p.a.n)$

s - Soil
c - Climate
o - Organisms (landcover & vegetation)
r - Topography
p - Parent Material
a - Age or time
n - Spatial location or position

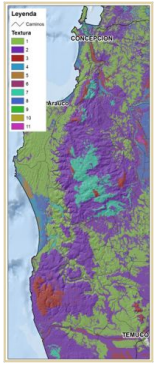


Sand [%]

Silt [%]

Clay [%]

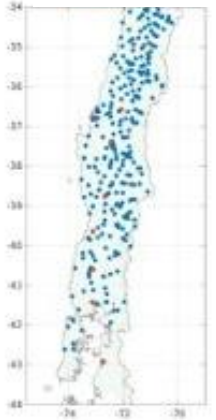
Soil Texture



Bulk density

Organic Matter [%]

Rainfall



Era40 ECMWF

Data each 6 hrs
1960-2003
Resolution ~100 km

Merra2

Hourly data
1980-2017
Resolution ~50 km

Interpolation analysis → Statistic correction → Aditional corrections

Legend

Rainfall (mm)

- 0 - 23
- 23 - 138
- 138 - 390
- 390 - 711
- 711 - 1.169
- 1.169 - 1.673
- 1.673 - 2.200
- 2.200 - 2.865
- 2.865 - 3.530
- 3.530 - 5.845

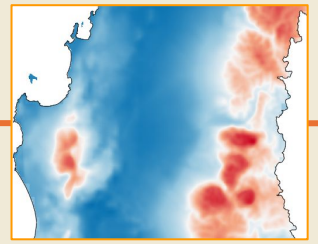
Material and methods

Factors estimation

Monthly rainfall (1988~2017)

Total anual rainfall (1988~2017)

Raster 500x500



$$R = \sum_{i=1}^{i=12} \left\{ 1.735 \times 10^{\left(1.5 \times log \frac{p_i^2}{p} - 0.8188\right)} \right\}$$

Factor R (Huang et al. 2020)

Base maps

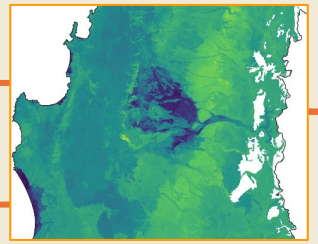
% Clay

% Silt

% Sand

Texture diagram

% Carbon



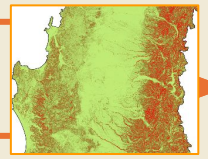
Factor K (Huang et al. 2020)

DEM 90x90

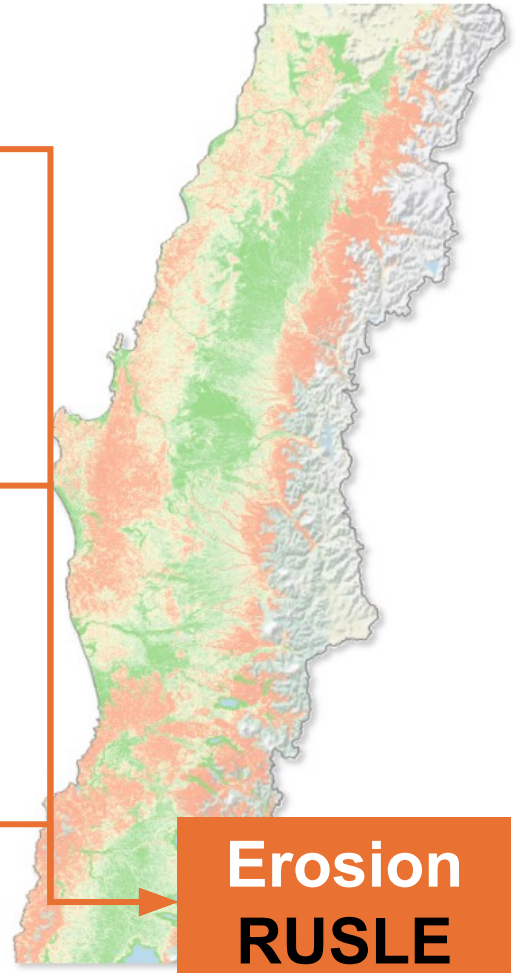
Sink filling

Slope inclination

Slope length



Factor LS (SAGA GIS)



Erosion RUSLE

Material and methods

Factors estimation

Cover and management factor C

C factor	Cover type	Source
0.001	Bush replaced by *Pinus radiata* plantation	Bonilla et al., 2010
0.00155	Broadleaves forests	Panagos et al., 2015
0.00155	Conifer forests	Panagos et al., 2015
0.006	Reforested bushes	Bonilla et al., 2010
0.009	Dense native forest	Bonilla et al., 2010
0.01	Bush replaced by *Eucalyptus* plantation	Bonilla et al., 2010
0.03	Semidense native forest	Bonilla et al., 2010
0.038	Meadow	Bonilla et al., 2010
0.045	Low productive grassland	Panagos et al., 2015
0.05	Non-dense native forest	Bonilla et al., 2010
0.055	Sclerophilous vegetation	Panagos et al., 2015
0.08	Agroforestry systems	Panagos et al., 2015

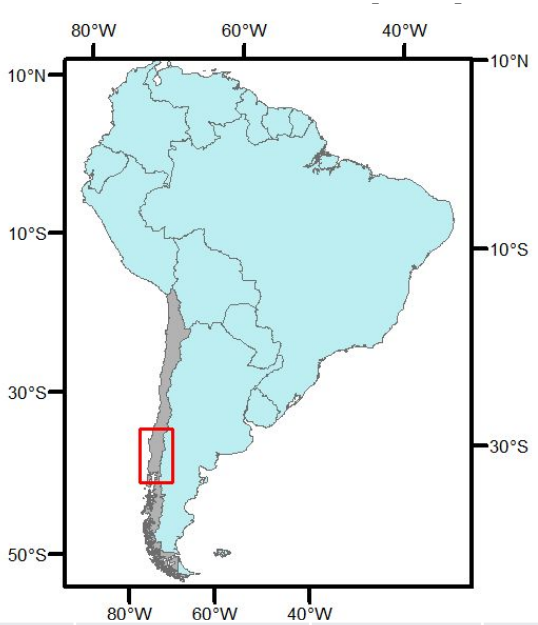
C factor	Cover type	Source
0.1	Dense grassland for cattle raising	Panagos et al., 2015
0.1	Agricultural soil	Bonilla et al., 2010
0.13	Mixed bushes	Panagos et al., 2015
0.2	Fruit trees or berries plantations	Panagos et al., 2015
0.2	Olive plantations	Panagos et al., 2015
0.21	Combined annual and perennial crops	Panagos et al., 2015
0.275	Sparse vegetation cover, steppe, tundra	Panagos et al., 2015
0.3	Wineyards	Panagos et al., 2015
0.325	Recently burned areas (wildfires)	Panagos et al., 2015

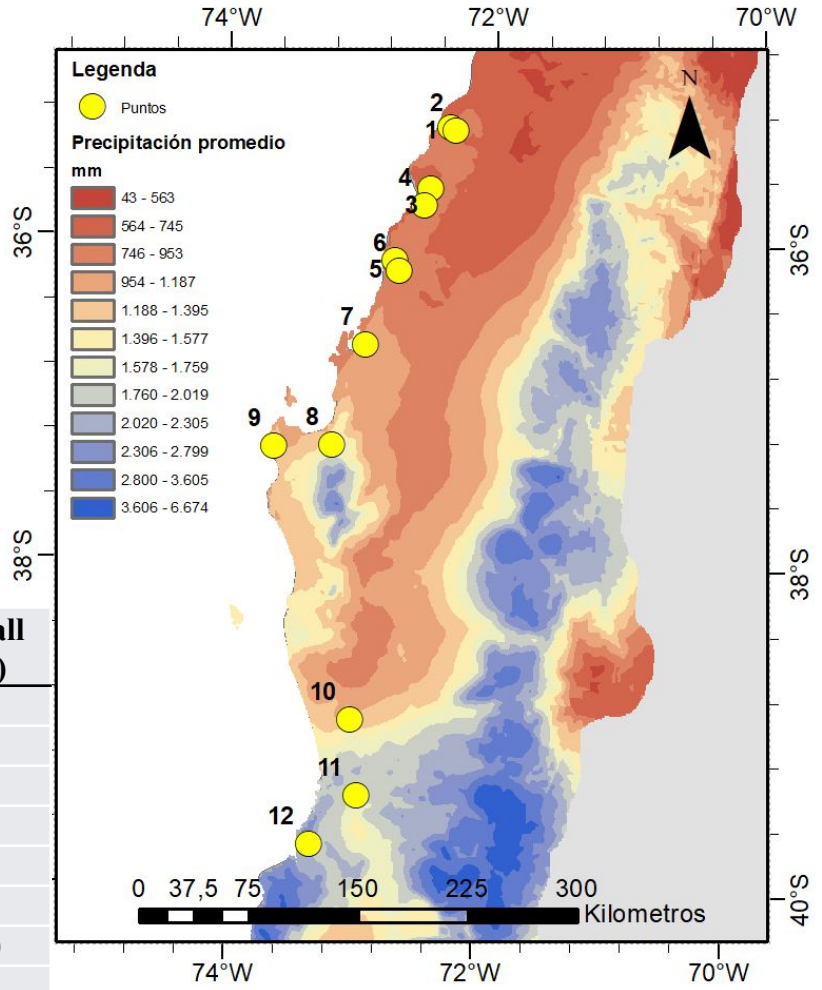
Bonilla, C. A., Reyes, J. L., & Magri, A. (2010). Water erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, central Chile. *Chilean Journal of Agricultural Research*, 70(1), 159-169.

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., & Montanarella, L. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Uuse Policy*, 48, 38-50.

Material and methods

Sites





Point	Name	Soil texture	Rainfall (mm)
1	Quivolgo AR	Clay	753
2	Quivolgo	Silty clay	771
3	Chanco	Clay	763
4	Pelluhue	Silty clay	815
5	Cobquecura AR	Clay	888
6	Cobquecura	Silty clay	870
7	Tomé	Silty clay	1080
8	Lebu	Silty clay	1244
9	Arauco	Clay	1670
10	Teodoro	Clay	1284
11	Mariquina	Clay	1747
12	Valdivia	Silty clay	2255

Sites selection

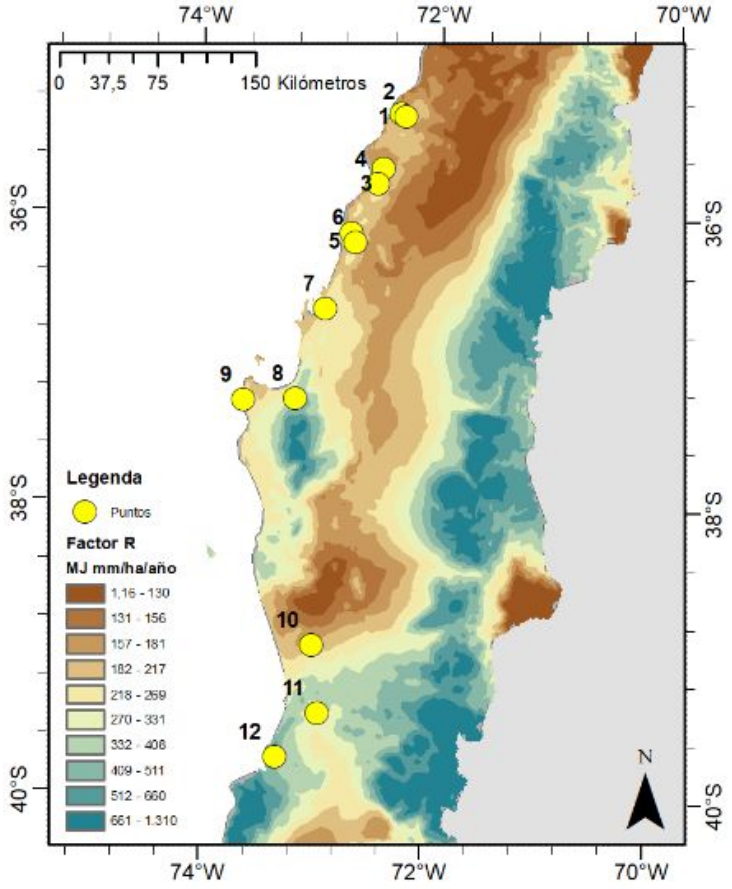
- 12 random sites
- In two textural classes
  - Silty clay
  - Clay

Sites characteristics

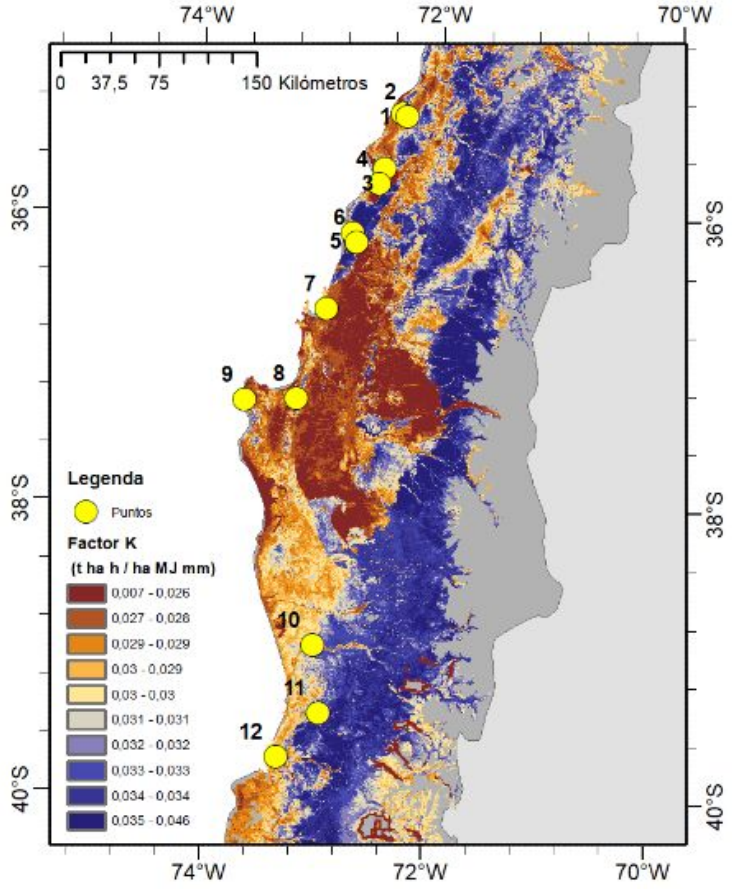
- Slopes between 15-20°
- On the coastal range
- Maule, BioBío, Araucanía and Los Lagos regions
- Central-south Chile

Material and methods

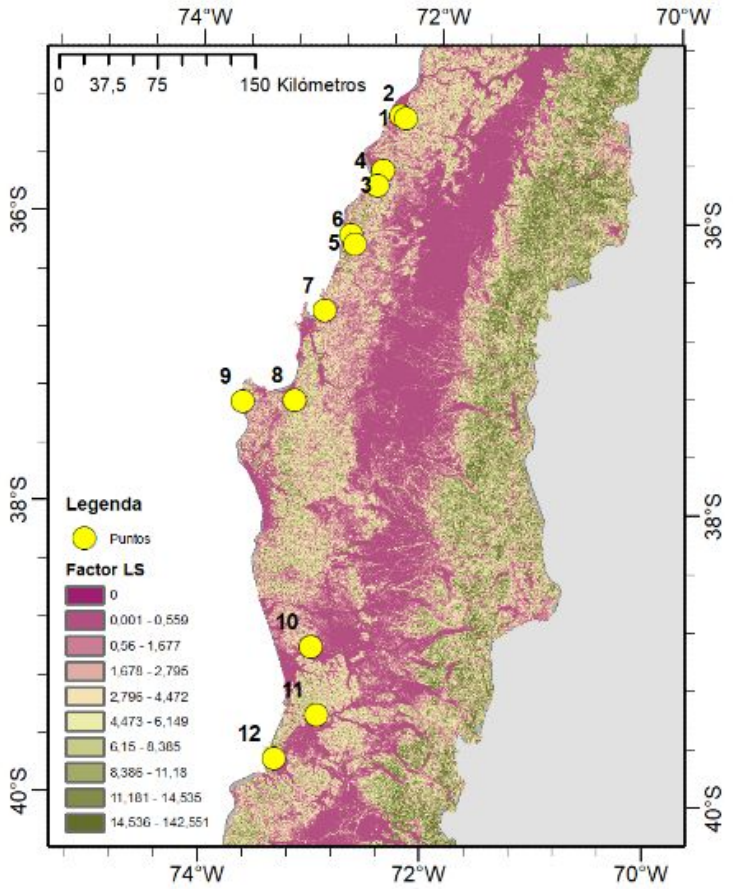
Rusle factors



Rainfall and runoff factor R

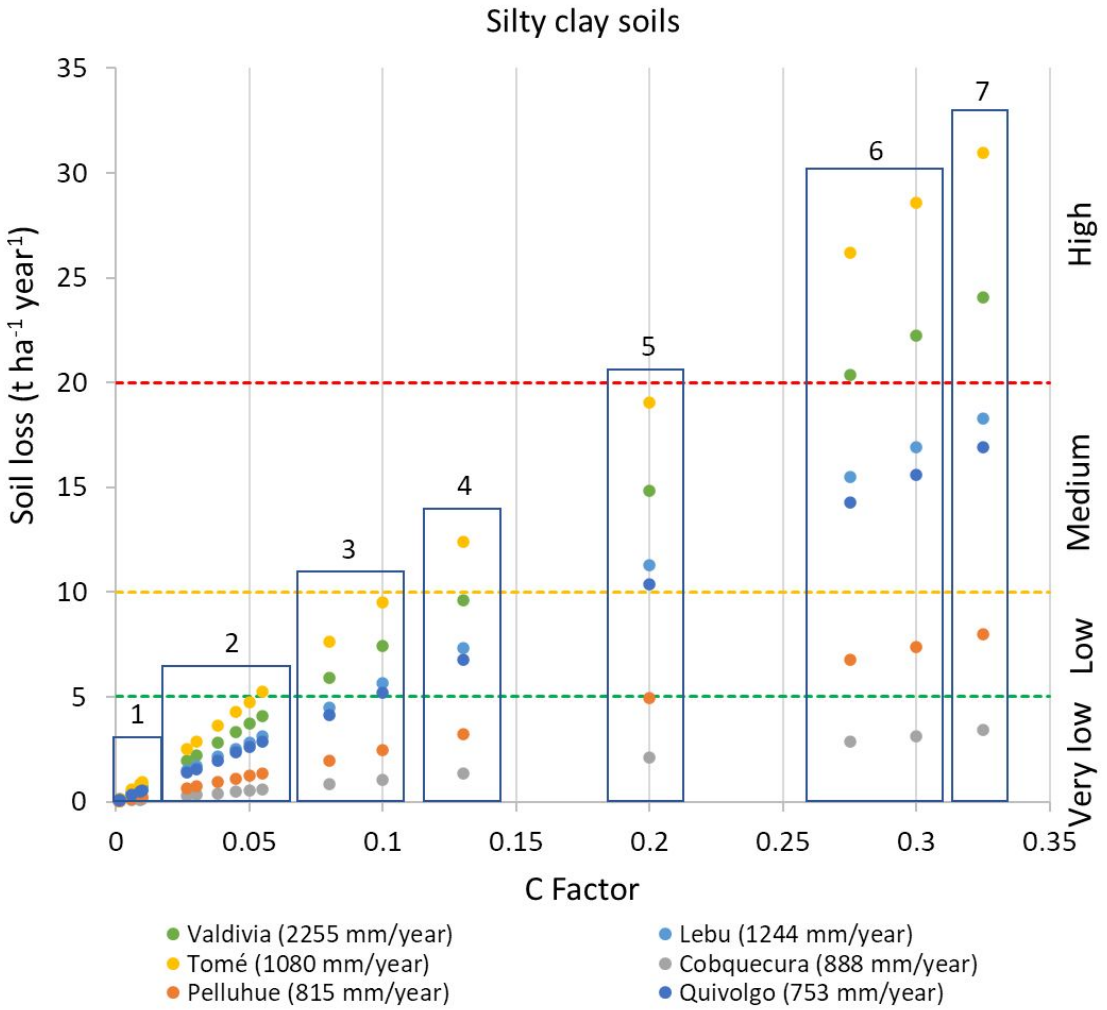


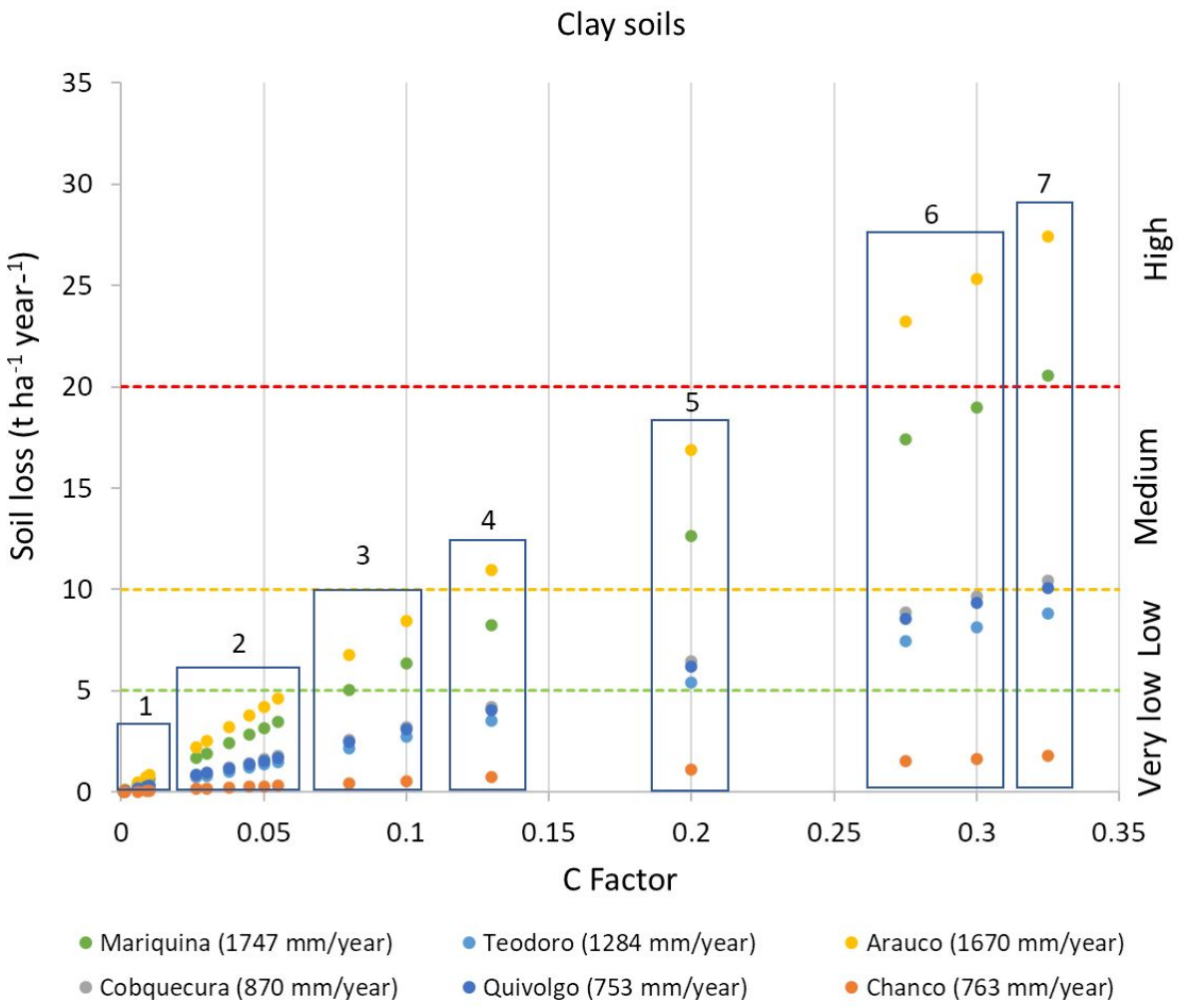
Soil erodibility factor K



Topographic factor LS

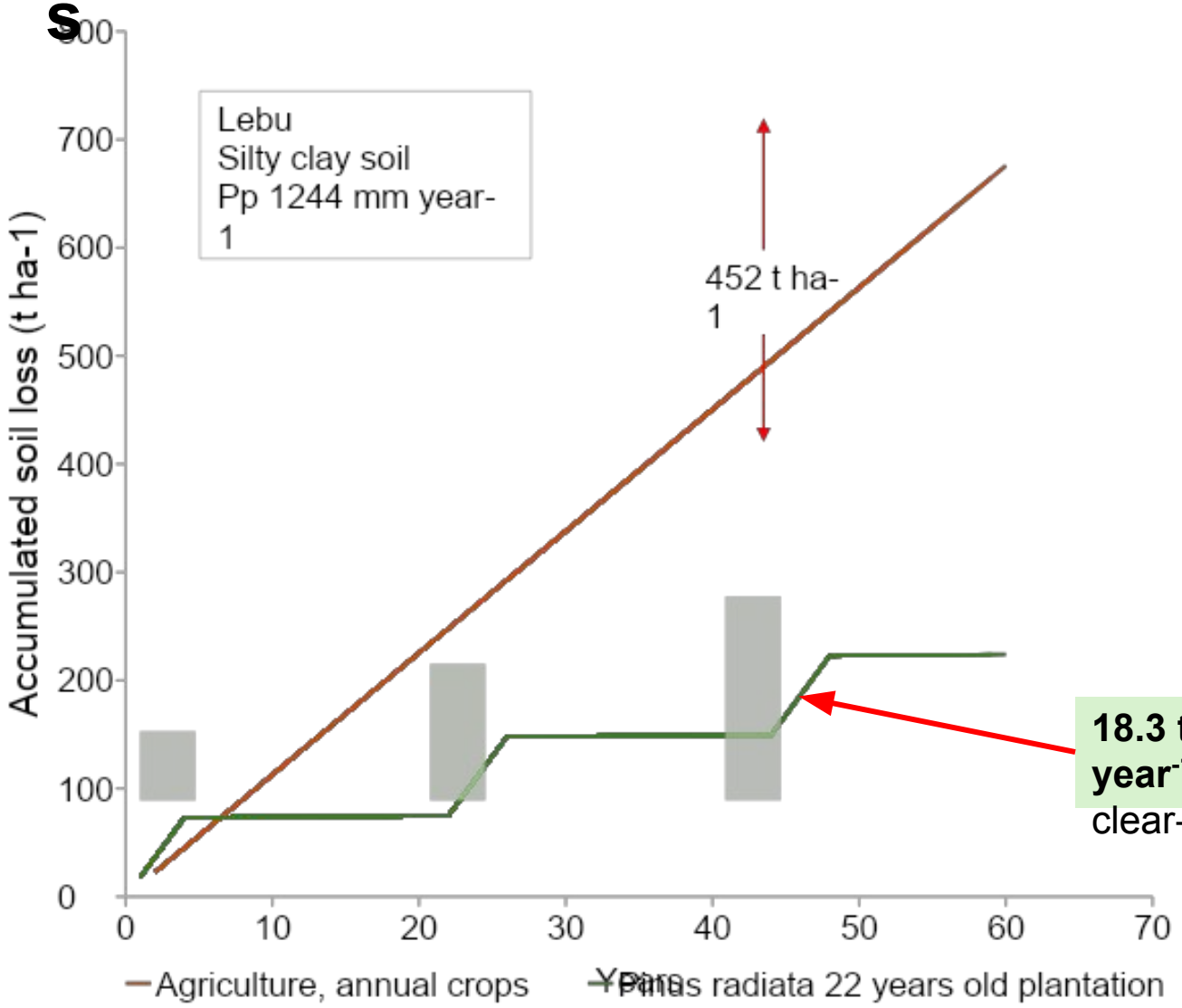
Result
s





1: Native forest and plantations
2: Semi-dense forest, meadows, sclerophyllous vegetation
3: Agroforestry systems, grassland for cattle raising
4: Mixed shrubs
5: Fruit trees and berries, olives, annual crops, combined with perennial crops
6: Sparse and degraded vegetation, vineyards
7: Recently burned land (wildfires)

Result
s



18.3 ton ha^{-1} year^{-1} after clear-cut

Importance of long-term evaluation: Analysis of soil loss accumulated on time illustrated by an example

Site Lebu (Biobío region, coastal range): 60 years simulation, *Pinus radiata* plantation with a rotation of 22 years, canopy closure at 4 years, versus annual crops (i.e. wheat)

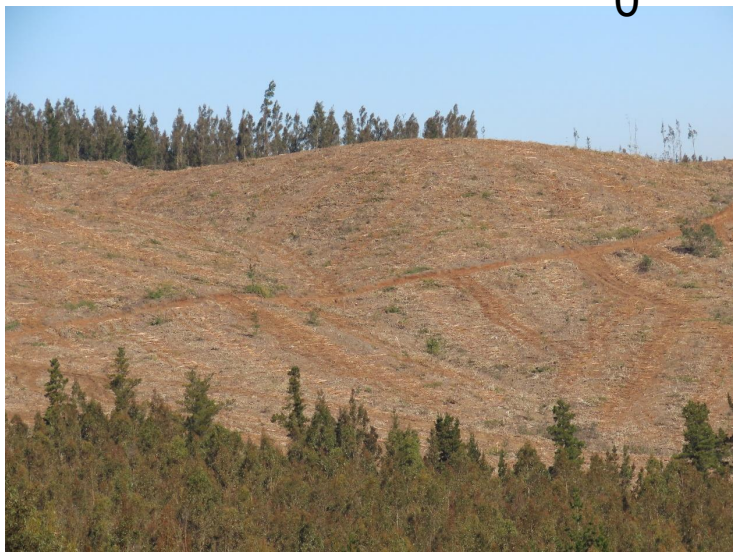
Simulation conditions: Use of the more extreme C factor between harvesting and canopy closure, **0.325** assuming 4 years of bare soil before canopy closure

Real data: range between
0.5 ton ha^{-1} year^{-1} (clear-cut with slash remaining) to
21.1 ton ha^{-1} year^{-1} (clear-cut with slash burning under 2570 mm year^{-1} and 30-60% slope)

Source: 6 field studies in Chilean plantations (Iroumé et al., 1989; Peña et al. 1993; Oyarzún and Peña, 1995; Niklitscheck and Gayoso, 2006; Huber 2009; Schuller et al., 2021)

Discussion

Long-term trajectory



Discussion

The plantation’s environmental contribution: soil conservation and soil regeneration

Final remarks

Importance of the example:
Contextualize the discussion about the forest plantations pros and cons

Clear-cut effect:
Specific and short-term events in the long term

Historical perspective and temporal analysis:
Considerable decrease in the accumulated soil loss in the long term

Plantation ecosystem services:
Degraded soils protection against erosion, organic matter and carbon fixation in the soil, protection of hydrological systems (regulation and less sediments), reduction of erosion rate 19-45 fold in comparison with agricultural systems

Under *Pinus radiata* A0 horizon, with granular structure, abundance of hyphae, microorganisms, and humidity

Final remarks

Next steps

- To develop latitudinal measurements to adjust the model to Chilean conditions
- Development of more precise tools for local decision support systems
- Generate evidence to contribute to the discussion of new public policies of soil management and conservation

Challenges

- Empirical nature of the RUSLE model and factors
- Risk of assuming inaccurate values without adjusting them to local conditions
- RUSLE simplicity allows its use with limited data

Perspective

- Comparative frame to evaluate production systems, soil cover, and conservation practices
- Preliminary indicators for possible future scenarios of the global climate change effect
- Emphasizes the importance of the sustainable use and management of soil in Chile

MUITO
~~OBRIGADA~~

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