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THE IMPACT OF MECHANICAL SOIL PREPARATION ON THE SURVIVAL AND GROWTH OF MARITIME PINE PLANTATIONS

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Groupe Pin Maritime du Futur

Scientific Interest Group

created in 1995 by 5 organisms:

- INRAE, CPFA, CRPF, FCBA, ONF

AIMS:

- Installation and long-term monitoring of forest experimentation networks on various subjects
- Recommendations for sustainable stand management
- Dissemination of results to the forest managers and the forestry sector

Les Landes de Gascogne forest = the largest planted forest in Europe covered by monocultures of Maritime pine (*Pinus pinaster* Ait.)

- Importance of the wood industry
- Dynamic sector
- Reliable models : improving sustainable silvicultural choices

Three main topics of the R&D programm

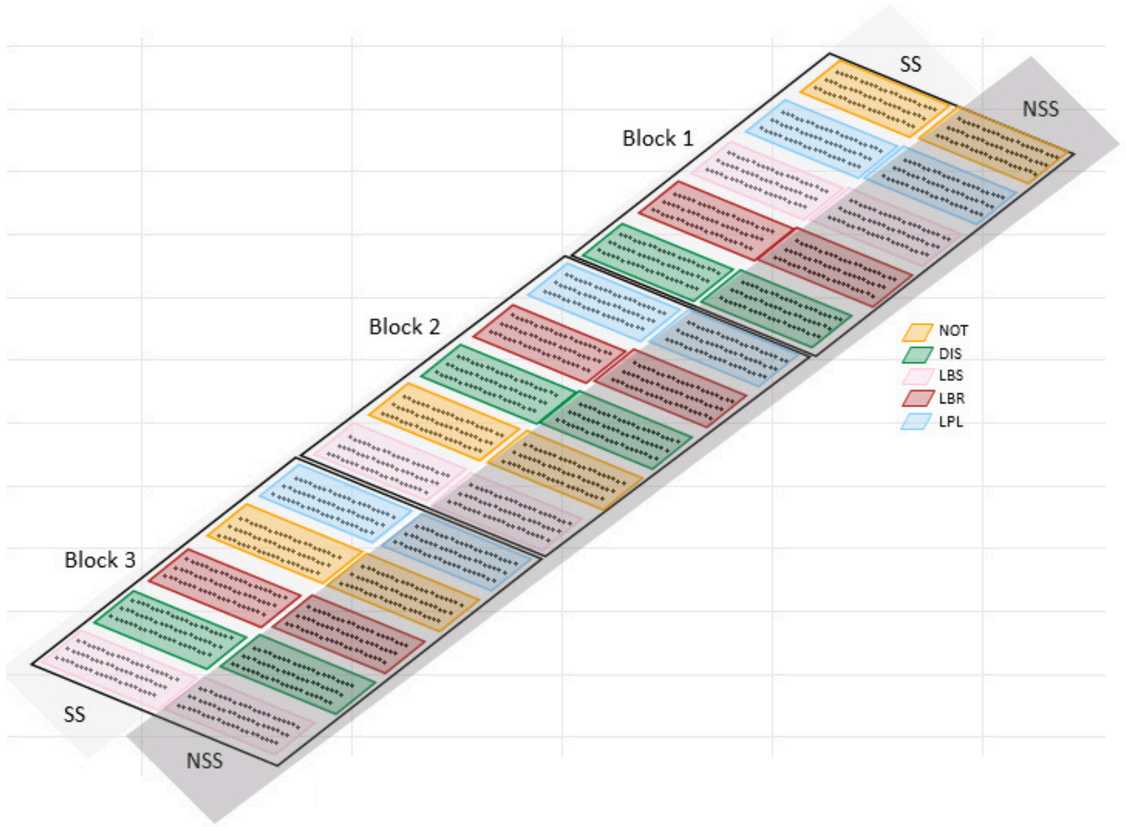
01 Adaptation of Maritime pine forest to different hazards

02 Improved varieties and selection methods

03 Silvicultural innovations for sustainable management of planted forests

Improved knowledge leads to better forest dynamics models for sustainable forest management

Experimental trial - experimental design and treatments



Experimental design : TRASOL network - Losse trial (40)

- Mechanical soil preparation: April, 2015
- Plantation of maritime pine seedlings : April, 2015

Factor 1 : deep soil preparation (~50 cm) -Trapro

- **Control - NSS**
- **Subsoiling - SS**

Factor 2 : shallow soil preparation (~10-30 cm)- Trasup

- **Control - NOT**
- **Disc harrowing - DISC**
- **Strip ploughing without inter-row tillage - LBS**
- **Strip ploughing with inter-row tillage after 2 years - LBR**
- **Full ploughing - LPL**

Randomized complete block design:
3 blocks with 10 plots each

Plot area: 0.1 ha, 5 rows of 25 trees
Tree density: 1250 t/ha (4 m x 2 m)

Experimental network - TRASOL network on MSP

Previous experimental results showed that
mechanical site preparation (MSP) increases both survival and growth of planted seedlings

No soil preparation

↘ Survival and growth of trees

Subsoiling

∅ No effects on the first stages of the plant growth

↗ Deep root system

Full ploughing

↘ Understorey plant cover

↗ Survival and growth of trees

↗ Wind stability of trees

∅ No effects on soil penetration resistance

?

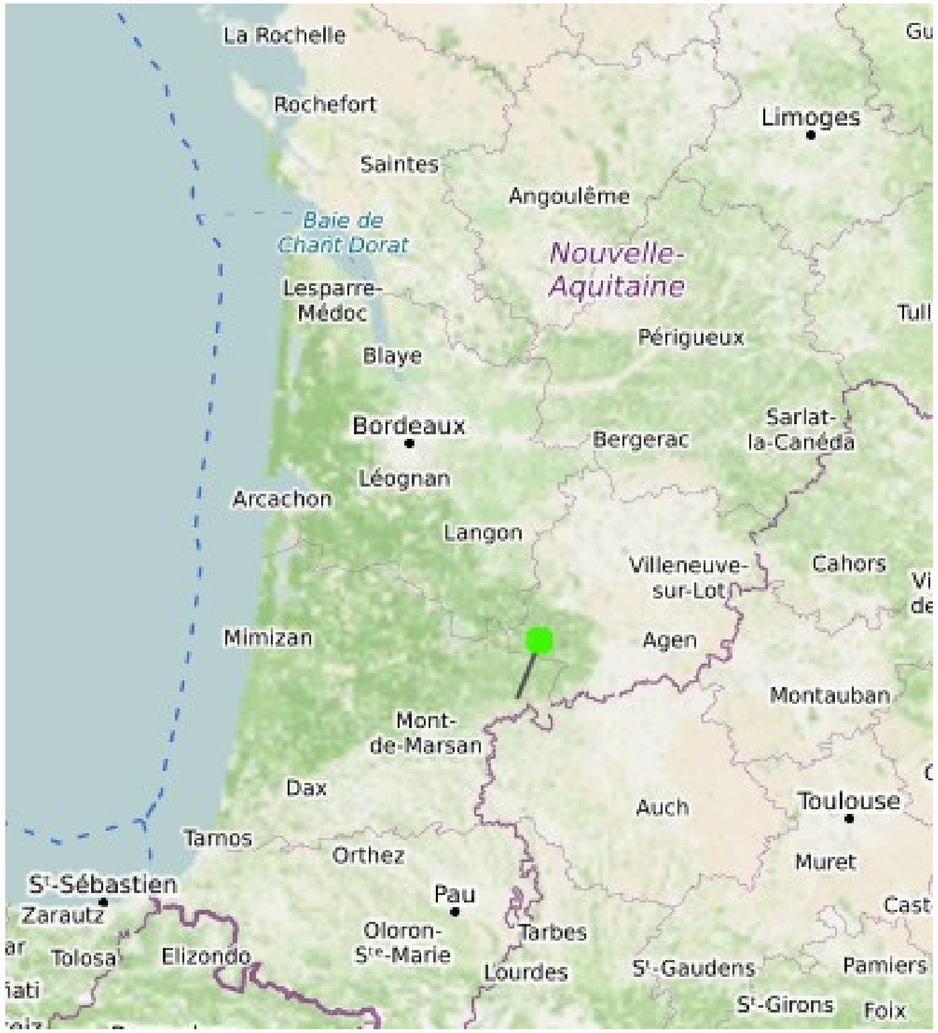
Trade-off between soil preparation intensity and pine productivity

Partial soil preparation = similar results of intensive soil preparation ?

Experimental trial - study area and weather conditions

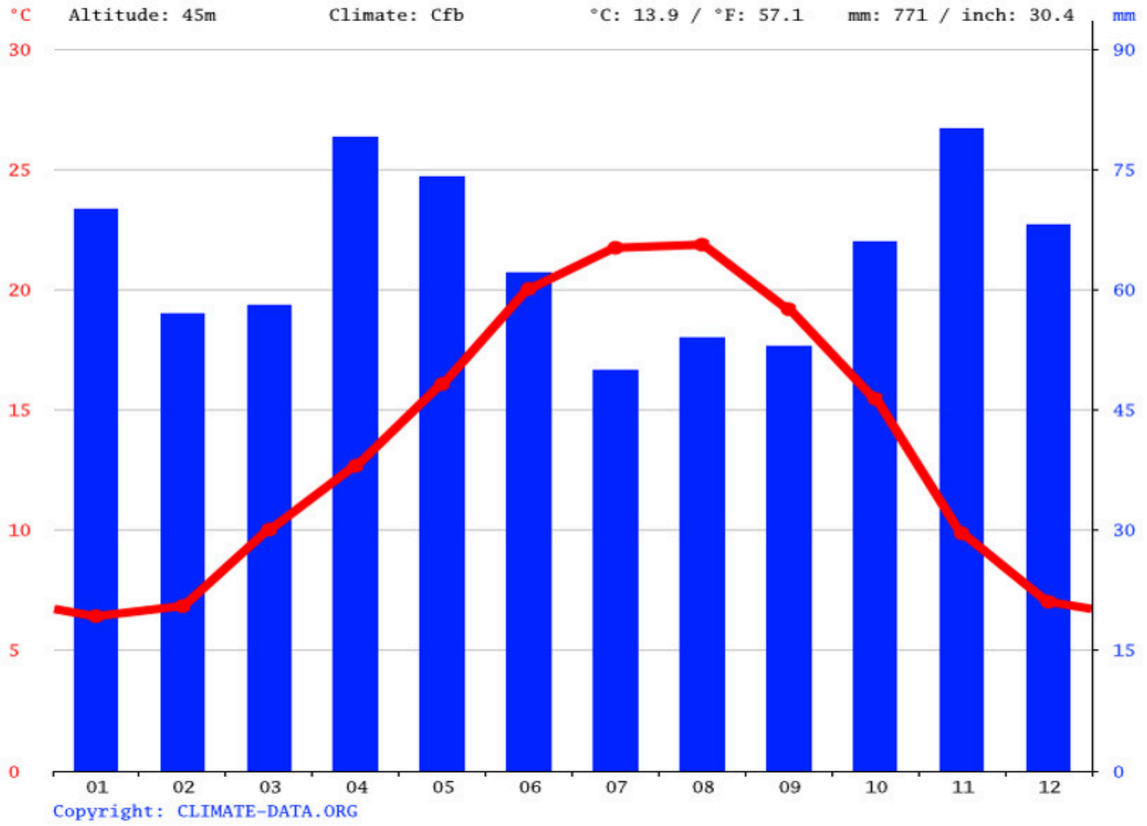
Trial location

SylvoEcoregion : Landes de Gascogne (F21)



Trial climate : 1991-2021

Cfb : Temperate oceanic climate (Köppen classification)



Materials and methods - measurements

Measured variables on trees (all planting trees)

Status

Status

- Healthy tree
- Dying tree
- Other damages
- Damage tree by wind (windfall or windsnap)
- Dead tree (Dry standing tree)
- Disappeared

Height

Vertical distance from the bottom of the tree to the final bud of the main stem

Equipment

- h < 10 m : pole
- h > 10 m : dendrometer

Girth

Permanent height (marked) = 1.30 m
Measured from the 7th year after planting

Equipment : steel tape

Materials and methods - measurements

Environmental measured variables

Soil resistance to penetration

5 measurement locations in all NSS plots and only in SS x LPL plots (severe MSP)

Equipment

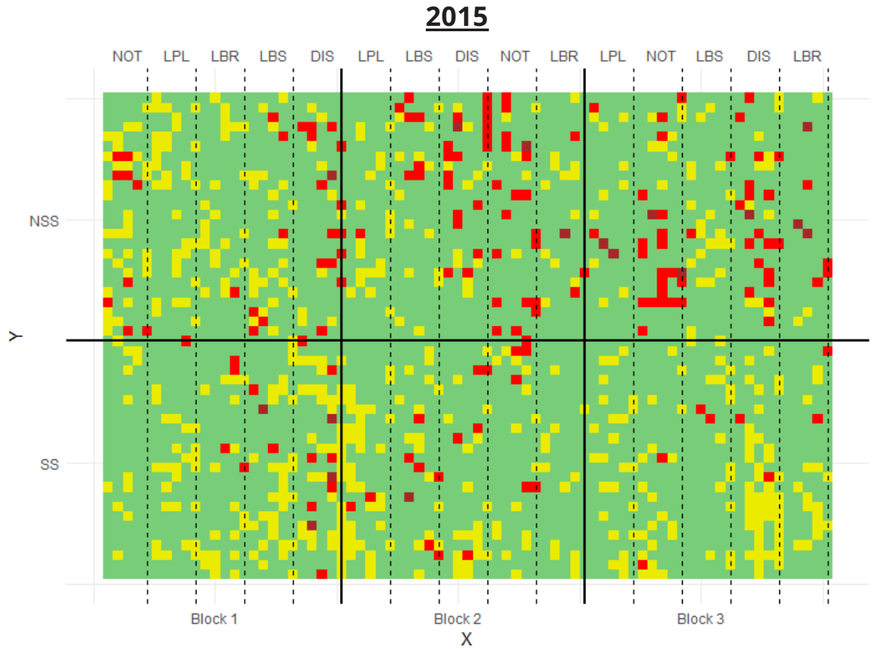
- PANDA: computer-assisted dynamic digital penetrometer

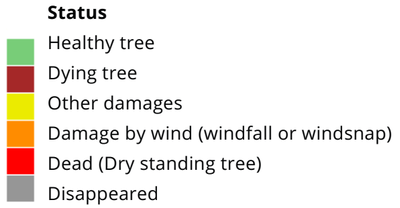
Soil cover

Subplots of 2 m² on planting rows and inter-rows
Measured in 2015, 2016 and 2017

- Percent cover of 4 categories:
  - Bare mineral soil
  - Humus
  - Slash and residues
  - Living vegetation

Results - tree survival : maps of tree status





Deep soil preparation (~50 cm) -Trapro

- Control - NSS
- Subsoiling - SS

Shallow soil preparation (~10-30 cm) - Trasup

- Control - NOT
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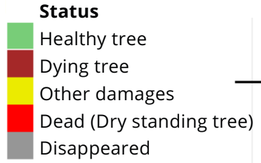
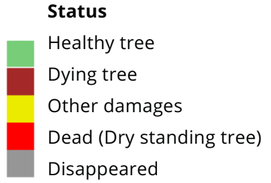
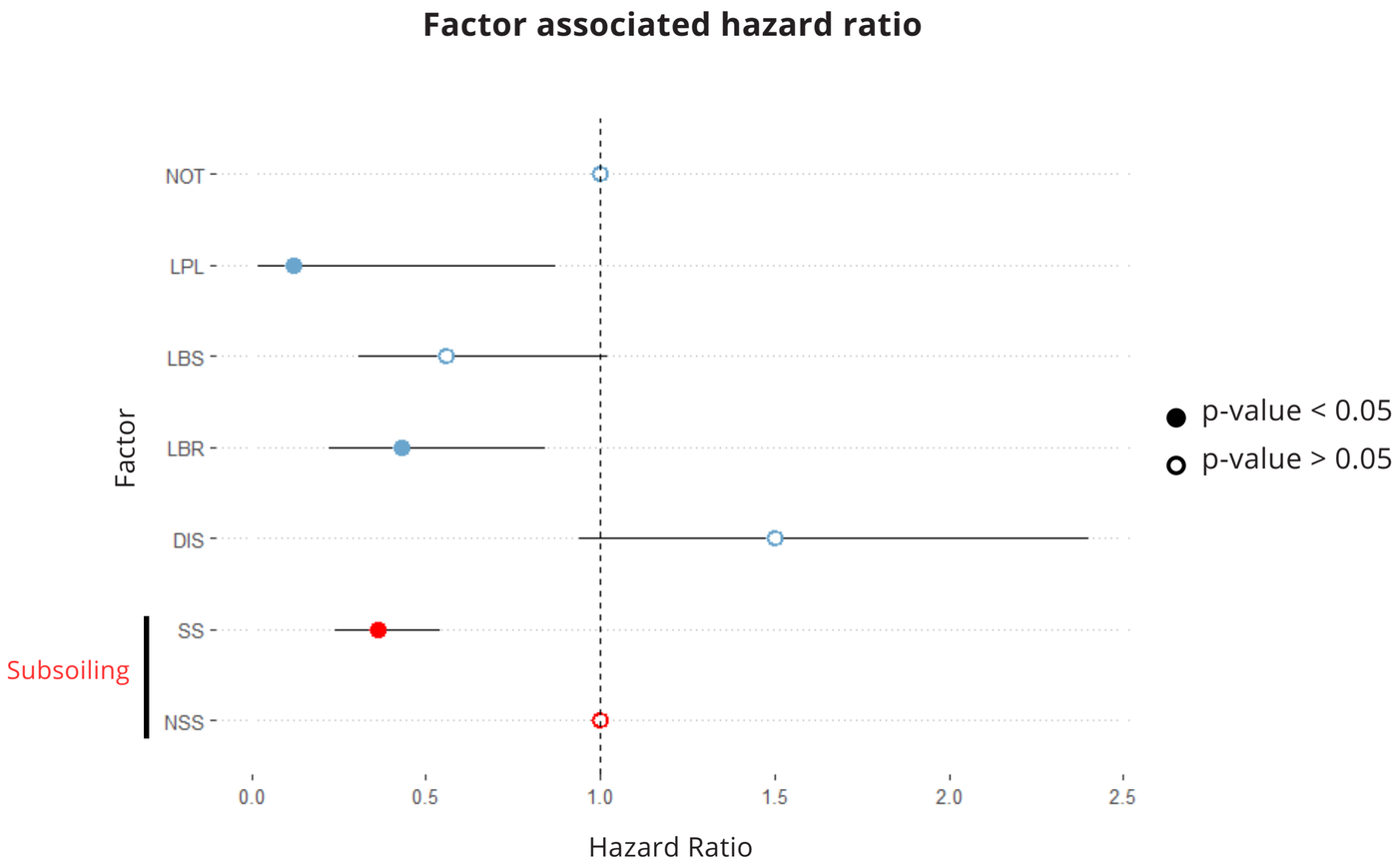




Results - tree survival

$$Mort\left(t\,;\ \mathrm{Trapro}_j,\ \mathrm{Trasup}_k\right) = Mort_0\left(t\right)\exp\left(\mathrm{Trapro}_j\ +\ \mathrm{Trasup}_k\right) \quad \left| \begin{array}{l} j \in \{1\,;\,2\} \\ k \in \{1\,;\,5\} \end{array} \right.$$



Study period = from 2015 to 2021

Cox model with interval censoring

↳ estimation of the date of death of trees at 2-year intervals

Significant effect of all explanatory variables ✓

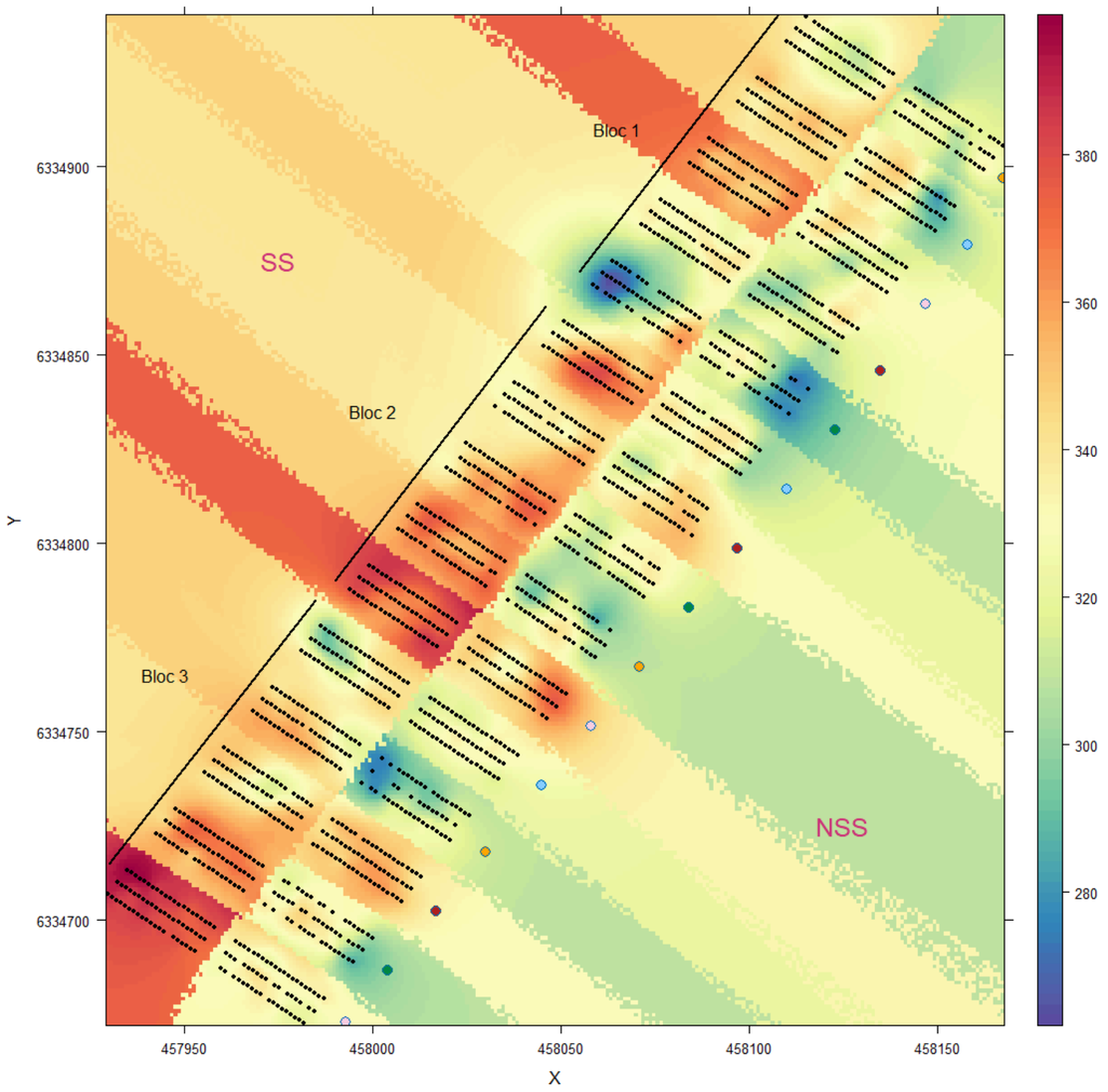
→ Significant positive effect of subsoiling (SS/NSS)
with a 64% reduction in the risk of death

→ Significant positive effect of the strip ploughing with inter-row tillage (LBR/NOT)
with a 57% reduction in the risk of death

→ Significant positive effect of full ploughing (LPL/NOT)
with a 88% reduction in the risk of death

Results - tree girth at 7 years old

Spatial interpolation of tree girth in 2021 as a function of soil preparation



$$Cir_{ijk} = a + \text{Block}_i + \text{Trapro}_i + \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j + \text{Block}_i : \text{Trasup}_k + \text{Trapro}_j : \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j : \text{Trasup}_k + \epsilon_{ijk}$$

$a = intercept$
$i \in \{1\,;\,3\}$
$j \in \{1\,;\,2\}$
$k \in \{1\,;\,5\}$

Significant effect of the 3-level interaction but low level of significance of the model ! ✓

R^2 = 0.089

→ Blocks 2 and 3 > Block 1
with an average difference of around 65 mm in the SS x DIS plots

→ Significant positive effect of subsoiling (SS/NSS)
with an average difference of around 45 mm

→ SS x LBR > SS x LBS
with an average difference of around 40 mm

→ SS x LBR > SS x LPL
with an average difference of around 35 mm

→ Significant positive effect of the strip ploughing with inter-row tillage SS x LBR (/NSSxNOT)
with an average difference of around 66 mm

LBR should be associated to SS

Results - heights

$$H_{iik} = a + \text{Block}_i + \text{Trapro}_i + \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j + \text{Block}_i : \text{Trasup}_k + \text{Trapro}_j : \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j : \text{Trasup}_k + \epsilon_{ijk}$$

$a = intercept$
$i \in \{1\,;\,3\}$
$j \in \{1\,;\,2\}$
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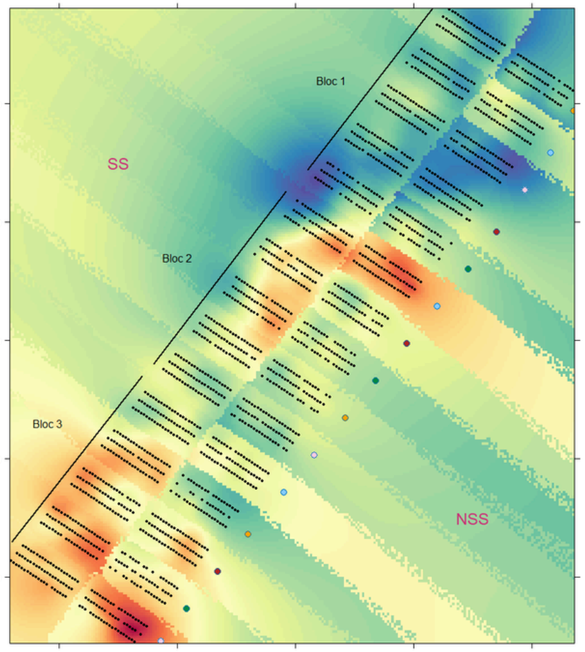
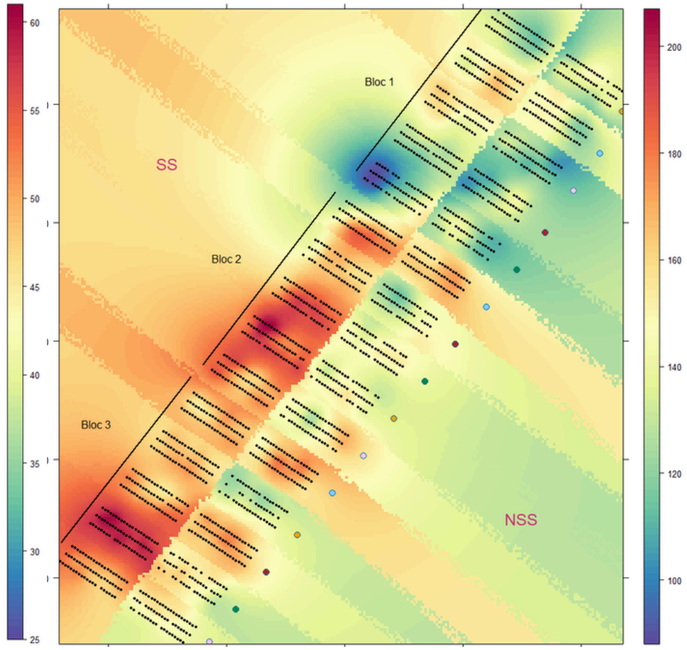
2015 - 1 year old



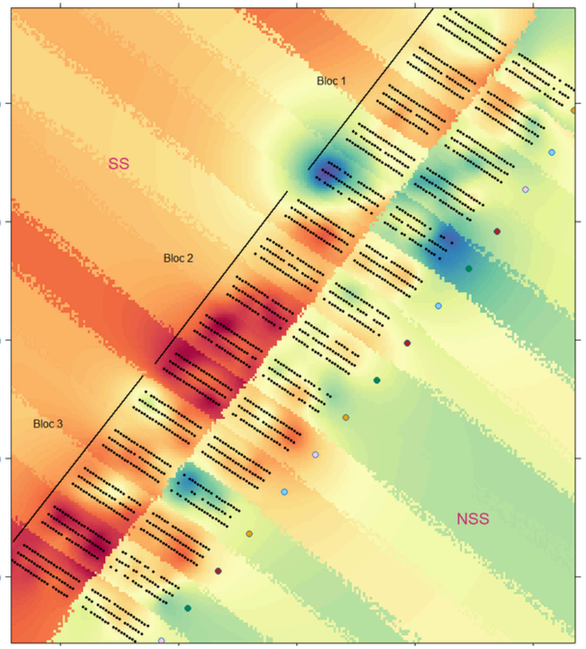


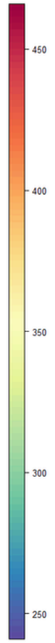
$R^2 = 0.29$

2017 - 3 years old

$R^2 = 0.29$

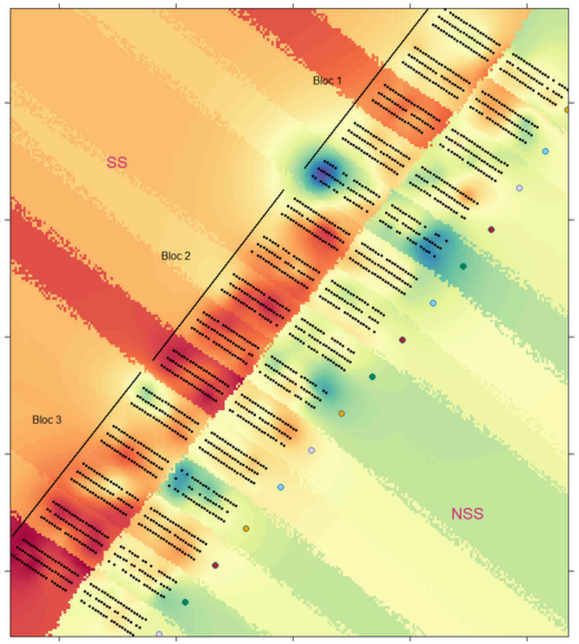
2019 - 5 years old





$R^2 = 0.26$

2021 - 7 years old



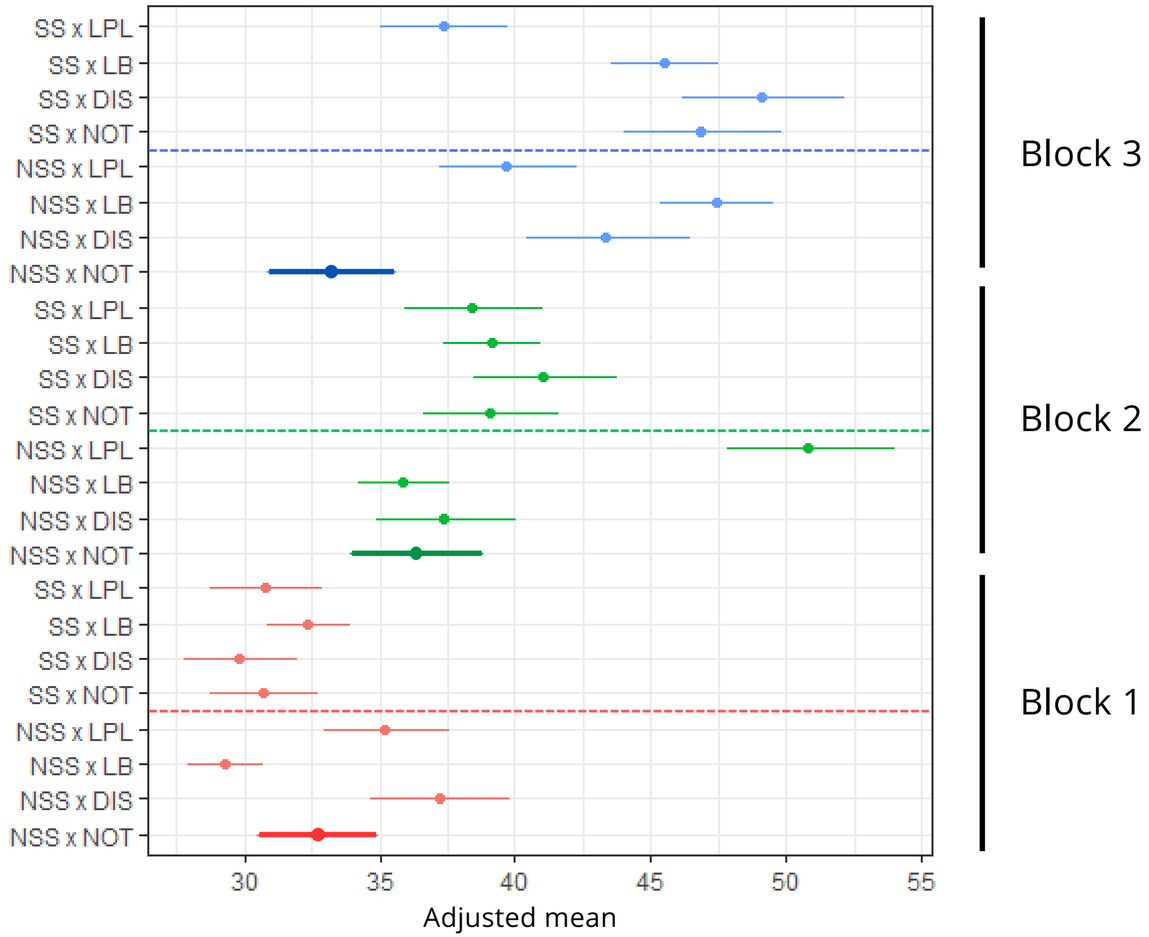
$R^2 = 0.22$

Results - heights

$$H_{iik} = a + \text{Block}_i + \text{Trapro}_i + \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j + \text{Block}_i : \text{Trasup}_k + \text{Trapro}_j : \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j : \text{Trasup}_k + \epsilon_{ijk}$$

$a = intercept$
$i \in \{1\,;\,3\}$
$j \in \{1\,;\,2\}$
$k \in \{1\,;\,5\}$

Adjusted average tree height in each plot in 2015



Significant effect of the 3-level interaction ✓

2015

→ Blocks 2 and 3 > Block 1, especially for NSS x LB and SS x DIS

→ No subsoiling effect

Results - heights

$$H_{iik} = a + \text{Block}_i + \text{Trapro}_i + \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j + \text{Block}_i : \text{Trasup}_k + \text{Trapro}_j : \text{Trasup}_k + \text{Block}_i : \text{Trapro}_j : \text{Trasup}_k + \epsilon_{ijk}$$

$a = intercept$
$i \in \{1\,;\,3\}$
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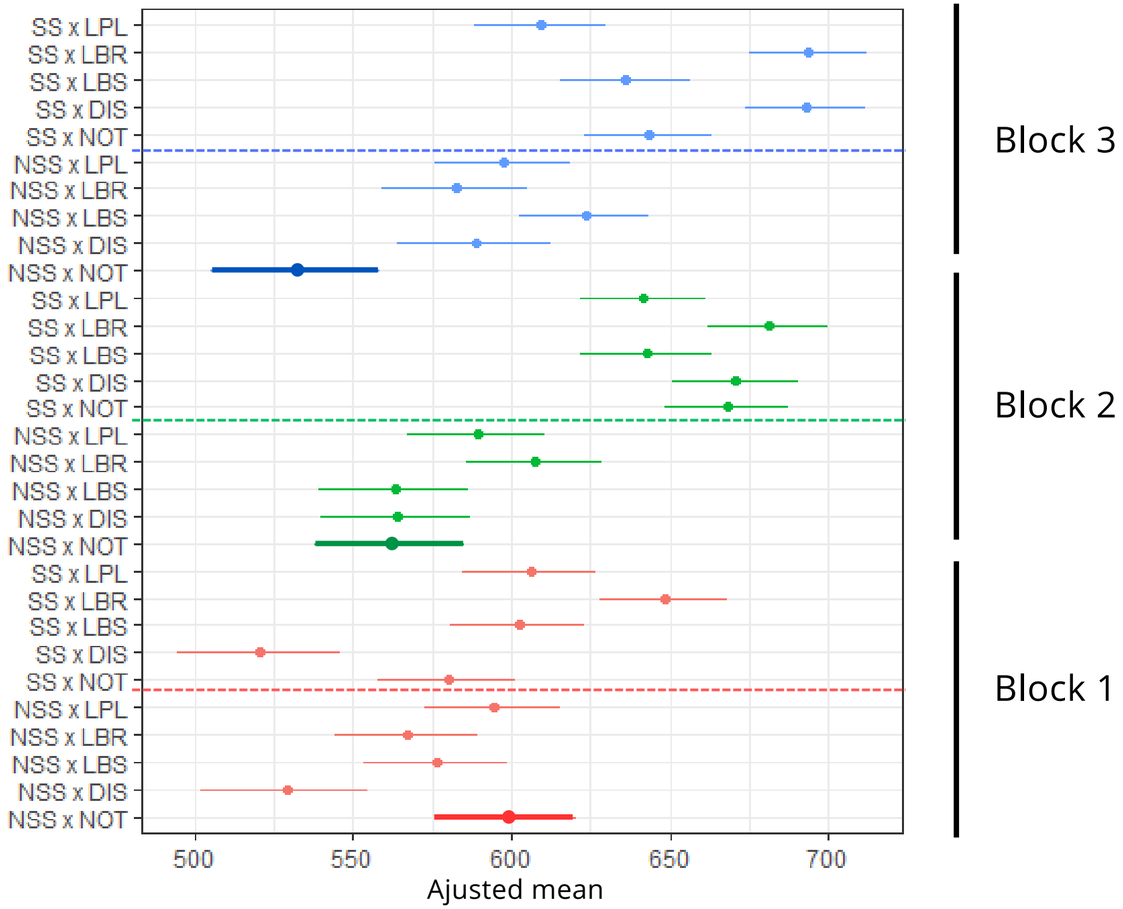
$k \in \{1\,;\,5\}$

Ajusted average tree height in each plot in 2021



Significant effect of the 3-level interaction ✓

2017-2019-2021

→ Highly variable response from disc harrowing plots depending on the block

↪ for NSS and SS subplots

2019-2021

→ SS x LBR > NSS x NOT
True for all blocks !
with an average difference of around 50 cm in block 1, and 139 cm in blocks 2 and 3 in 2021

→ NSS x LPL > NSS x NOT only for block 3 !

→ No significant effect of SS x LPL (/SS x NOT)

Results - soil resistance

$$Res_{ikl} = a + \text{Block}_i + \text{Trasup}_k + \text{Depth}_l + \epsilon_{ikl}$$

$a = intercept$
$i \in \{1\,;\,3\}$
$k \in \{1\,;\,5\}$
$l \in \{1\,;\,5\}$

R^2 = 0.55

Significant effect of all explanatory variables ✓

Average soil resistance according to depth and soil preparation

Deep soil preparation (~50 cm)
-Trapro
- Control - NSS
- Subsoiling - SS

Shallow soil preparation (~10-30 cm)
- Trasup
- Control - NOT
- Disc harrowing - DIS
- Strip ploughing without inter-row tillage - LBS
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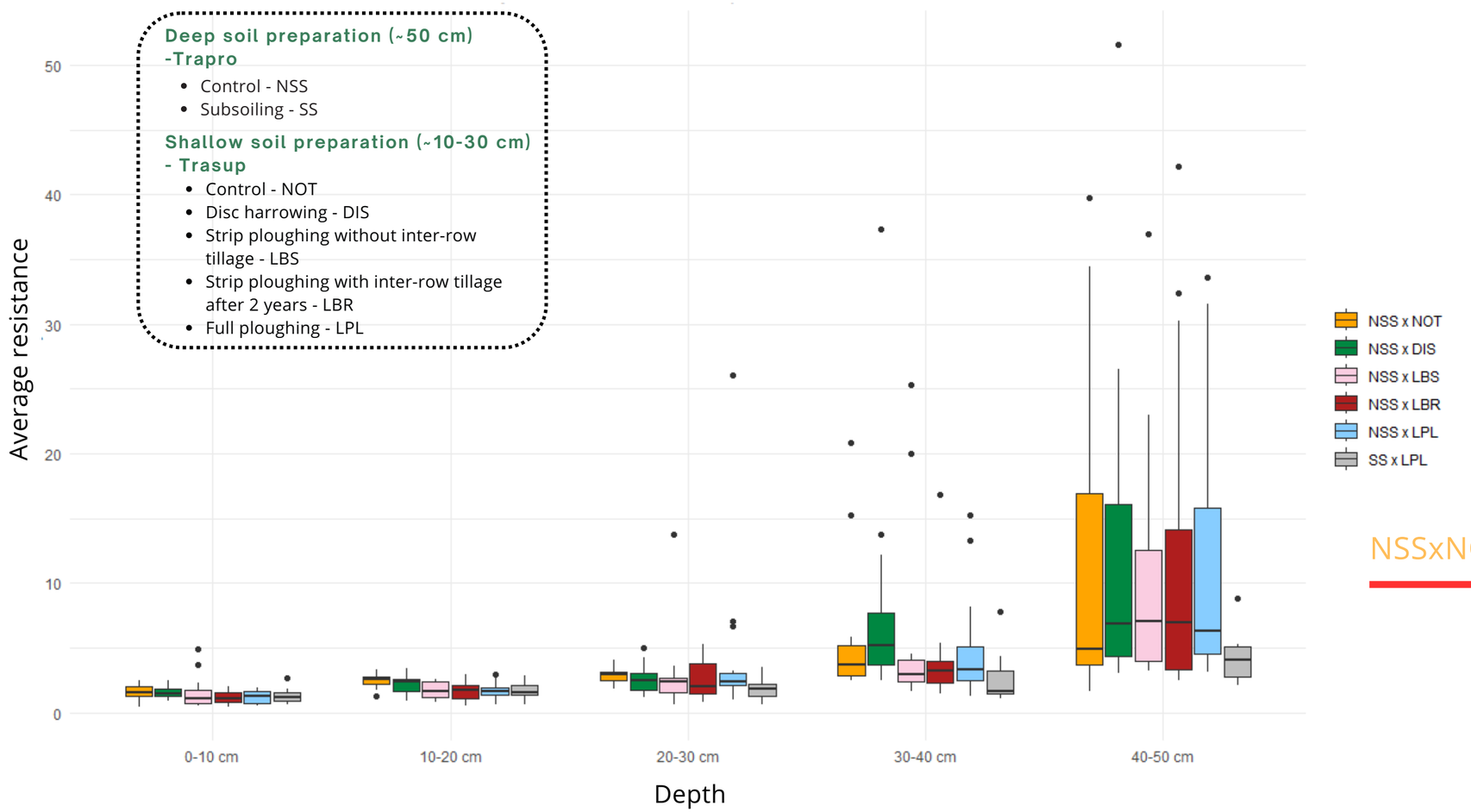


→ **Depth class :** resistance to penetration increases significantly with depth (for the same sandy texture)

→ SSxLPL reduces resistance to soil penetration even at the greatest depth

BUT

NSSxNOT NSSxDIS NSSxLPL NSSxLBS NSSxLBR SSxLPL

→ NSS x LBR = SS x LPL

→ NSSxLBR = all types of ploughing

Results - soil covering

$$Soil\ covering \sim Beta(\mu, \phi)$$

$$g(\mu) = \beta_0 + \beta_1 \cdot \text{Block} + \beta_2 \cdot \text{Trapro} + \beta_3 \cdot \text{Trasup} + \beta_4 \cdot \text{Planting rows}$$

$$h(\phi) = \gamma_0 + \gamma_1 \cdot \text{Block} + \gamma_2 \cdot \text{Trapro} + \gamma_3 \cdot \text{Trasup} + \gamma_4 \cdot \text{Planting rows}$$

	2015							2016							2017						
	Block		Trapro	Trasup			Planting rows	Block		Trapro	Trasup			Planting rows	Block		Trapro	Trasup			Planting rows
	1	2		DIS	LB_	LPL		1	2		DIS	LB_	LPL		1	2		DIS	LB_	LPL	
Vegetation	+	−											−		−		−	+		−	
Bare soil		+		−		+	+	+			−		+		+		+	−		+	
Humus			−	+		−	−			−				−			+				
Residuals				+		−	−	−			+		−	−			−				−

Discussion

This experimental trial is complex, as there are interactions between factors and blocks

Control-NOT: reduces survival

no significant differences with other modalities for tree size, especially associated with subsoiling

Disc harrowing-DIS : variable for survival and growth → Not recommended, even associated with subsoiling

↘ bare soil ↗ residue with **+ + variability**

Full ploughing-LPL: improves survival ↘ understorey vegetation, humus, residue and ↗ bare soil

NSS

- Survival : LPL > LBR > LBS
- Tree size : LPL = LBR = LBS

SS : bigger tree size

- LBR > LPL = LBS

Subsoiling : improves survival and tree size for blocks 2 and 3

Subsoiling and strip ploughing with inter-row tillage ↘ resistance to soil penetration

↪ **better root exploration**

Synthesis and perspectives

Severe MSPs (SS + (LP or LB))

- has a high lag effect in the recovery of understorey vegetation.
- appears as an option to obtain a high early seedling survival; but even in NSSxDISC the survival is >80%.
- will not provide stronger growth dynamics in all environments.
- has a financial cost that must be balanced against its beneficial effect on seedling survival and growth.

Next analysis:

- Floristic differentiation and level of soil disturbance
- Last measurements at 10 years old (2024) : survival, height, girth and basal deviation from verticality

Mechanical site preparation (MSP) is widely performed around the globe to enhance the success of forest plantations.

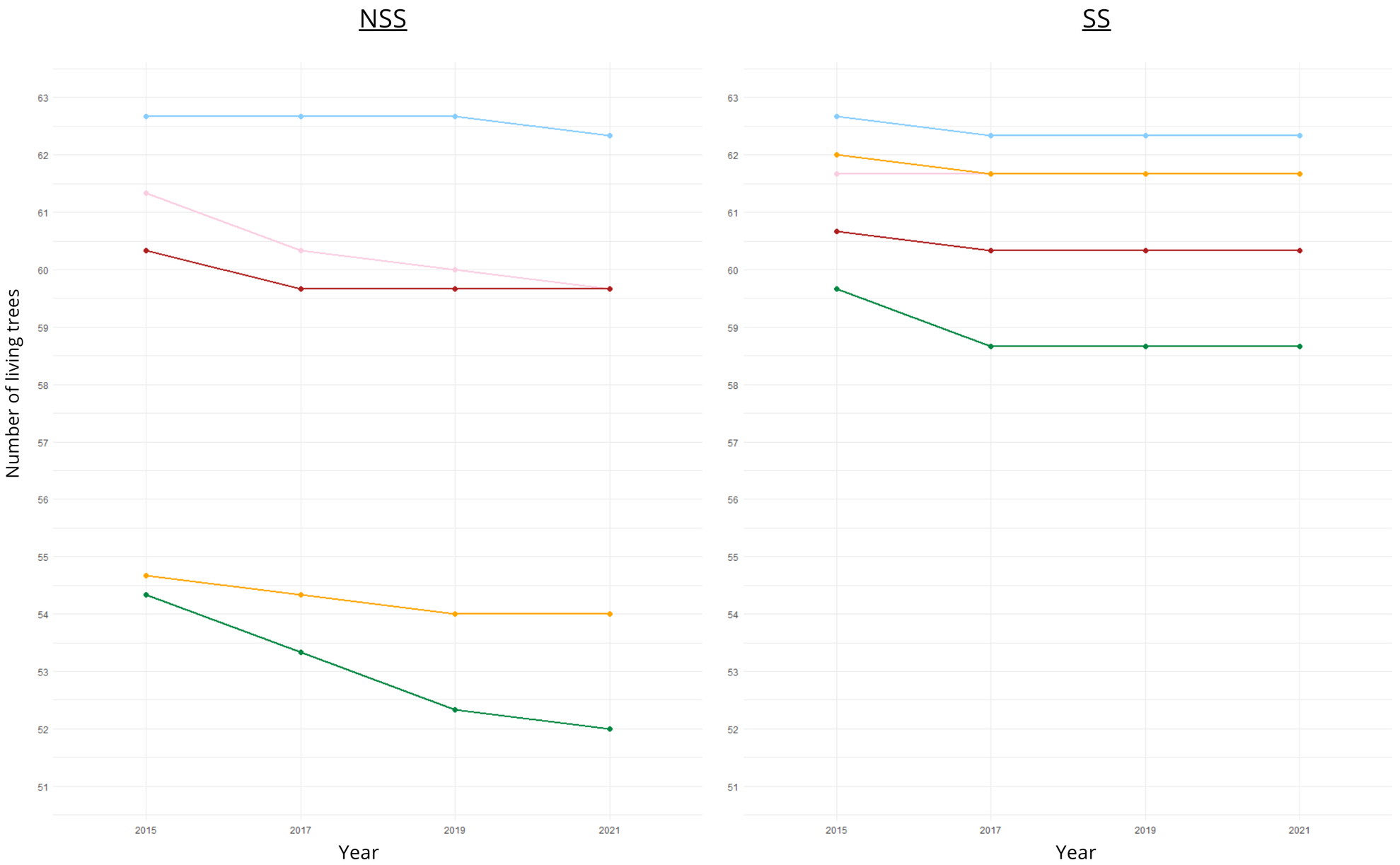
Our aim: Prompt pine forest managers to select silvicultural methods that allow seedling survival, dynamic early growth and preserve both soil and biodiversity.

Conclusion

Thank you for your attention !

Any questions ?

Results - tree survival : number of living trees



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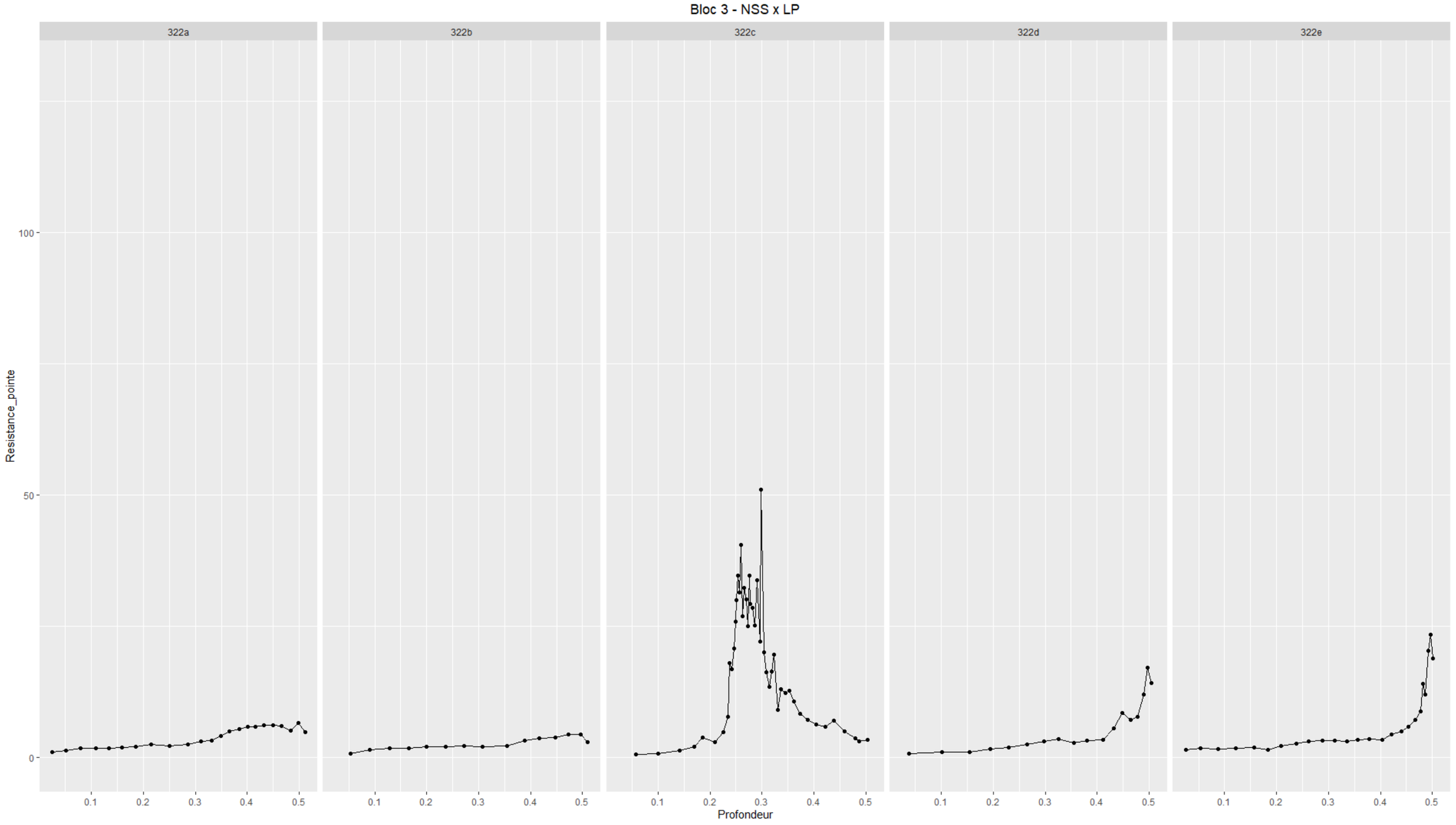
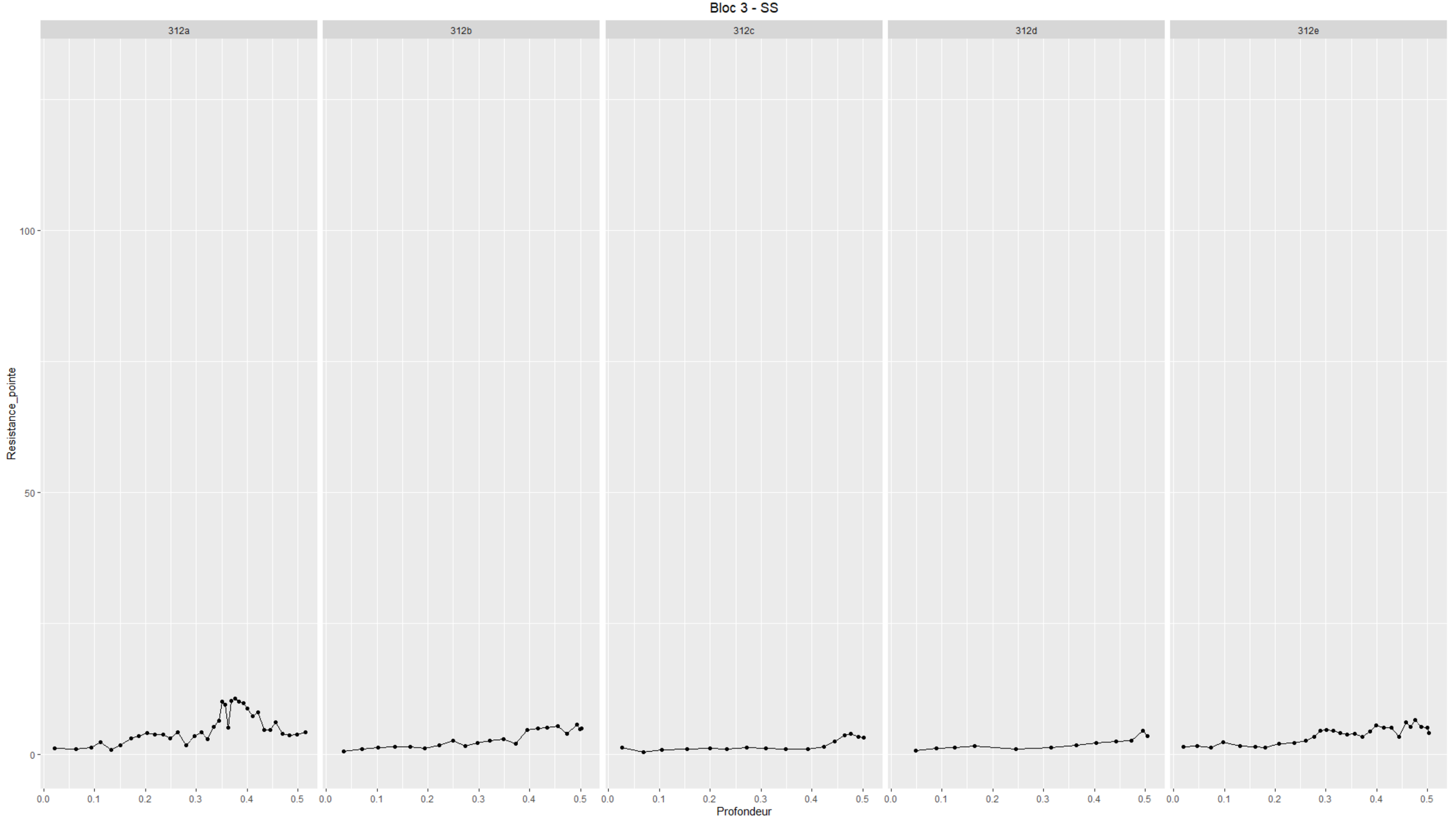

Bloc 3 - NSS x LP
322a
322b
322c
322d
322e
Resistance_pointe
100
50
0
0.1
0.2
0.3
0.4
0.5
Profondeur


Bloc 3 - SS
312a
312b
312c
312d
312e
Resistance_pointe
100
50
0
0.0
0.1
0.2
0.3
0.4
0.5
Profondeur