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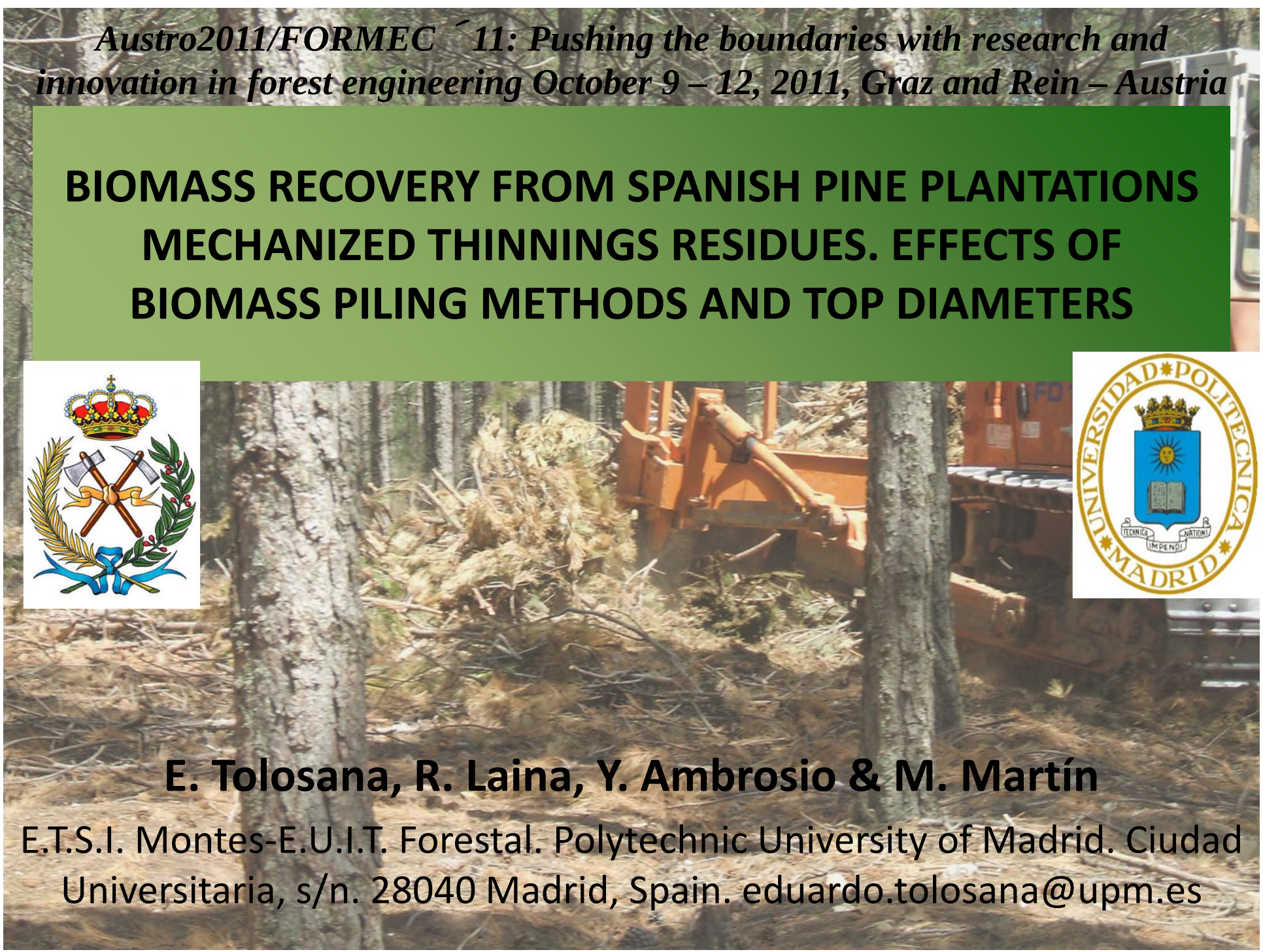
BIOMASS RECOVERY FROM SPANISH PINE PLANTATIONS MECHANIZED THINNINGS RESIDUES. EFFECTS OF BIOMASS PILING METHODS AND TOP DIAMETERS



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SPANISH PINE PLANTATIONS

- Afforested or reforested area **1940–1993**: more than 3.5 million hectares (**conifers: 2.937.000 ha**, mainly *Pinus pinaster*, *P. halepensis* and *P. sylvestris*)
- Afforested surface on marginal agricultural lands - **European Common Agricultural Policy (1994-2008)**: **657.000 hectares** - conifers + hardwood species -, plus > **900.000 ha additionally planted on public forests**.
- **Summing up *Pinus pinaster* and *P. radiata* private-owned plantations out of UE CAP, almost 5 million ha** covered with conifer plantations in Spain.
- **Potential production from thinnings is much greater than present fellings, is there an opportunity based on new biomass markets for energy?**

BIOMASS FROM PINE PLANTATIONS THINNINGS

- **WTH** (Whole Tree Harvesting) system = **most extended alternative** for biomass from early thinnings in Nordic countries.
- **Spanish tariffs** for energy from forest biomass **only subsidize woody crops and residual biomass**, so **collecting forest residuals from thinnings after forwarding roundwood** is a possible worksystem alternative to WTH
- **Profitability** in biomass collection from mechanized integrated thinnings is **conditioned by residuals weight per hectare –** the greater amount, the better **– and by branches and tops sizes –** the greater, the better.
- **These two factors are unfavorable in thinnings, even if strongly delayed**, **Could some changes in the operational organization help?**

STUDY MAIN GOALS

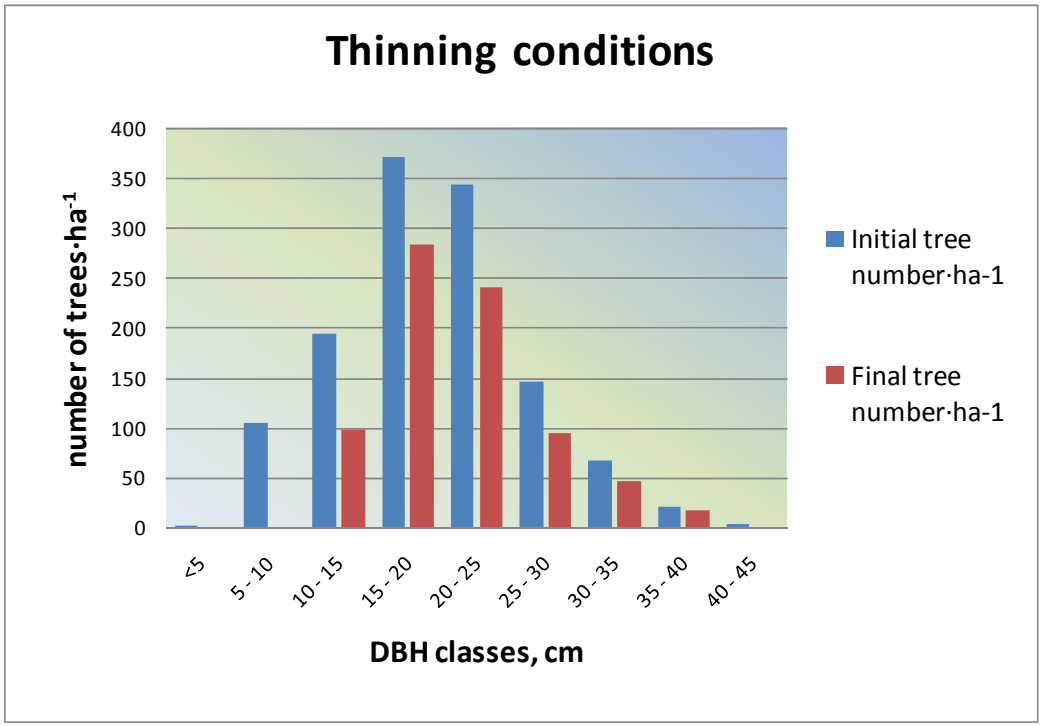
- **Compare two residuals bunching methods combined with mechanized CTL wood harvesting system in thinnings**: using the harvesting head to leave them piled along the strip road sides (**method S**) or leaving them on the strip road center, bulldozing them afterwards on bunches (**method C**), before hauling them off.
- **Compare two top diameters** separating tree tops used as biomass for energy from wood logs, 8 cm (Ø8) and 10 cm (Ø10).
- For doing it, develop a **methodology for comparing the global profitability** of such work systems, despite the different yields of various products that impede to compare productivities or unit costs. This mixed shredded biomass and roundwood harvesting system has been analyzed **using the *criterium* of maximizing the economic balance *per hectare***.

FIGURES FROM THE COMBINATION METHOD/Ø C8

FIGURES FROM THE COMBINATION METHOD/Ø S10

MATERIAL AND METHODS

- **18 permanent plots inventoried in a mixed artificial stand with *Pinus sylvestris*, *P. nigra* and *P. Pinaster* in Castilla y Leon Region.**



- **Time was classified using the IUFRO standards, with the table formats developed by the European Concerted Action AIR3-CT94-2097 .**

MATERIAL AND METHODS (II): STUDIED MACHINERY

Operation	Machine type - mark / model		Power (kW)	Payload / other features
Felling - Processing	Harvester	Timberjack	160	----
		John Deere 1270 D	160	----
Timber hauling-off	Forwarder	Dingo 6x6	89	16 m^3
Biomass hauling-off	Forwarder	Timberjack 1410 D	129	17 m^3
Biomass bunching (System C)	Bulldozer	Fiat-Hitachi FD 175	140	Raking front implement
Crushing	Schredder	Hammel VB 950	522	----

MATERIAL AND METHODS (III): TIME STUDY METHODS

- For **wood and biomass forwarding**, the **elemental measurement** was used, **with a Psion Workabout® hand-held computer and the purpose-designed software Kronos 3.0®** (Ambrosio & Tolosana, 2007).
- **For not cyclical operations** – biomass bunching by bulldozer or biomass shredding –, and for **wood felling and processing**, the elemental measurement was carried out by **work sampling, during one hour intervals that were treated as "treatment replications"** for each combination of (harvesting method x top diameter).
- **The correspondent treated surface and/or volume - weigh extracted were measured**.

Operation	Control method	Attendance controlled time (hours)	Attendance controlled time (work days)
Felling - Processing	Work sampling	94	7
Timber hauling-off	Elemental measurement with hand-held computer	30	3
Biomass hauling-off	Idem	33	4
Biomass bunching (System C)	Work sampling	17	2
Crushing	Work sampling	18	3

MATERIAL AND METHODS (IV)

COMPLEMENTARY BIOMASS CHARACTERISTICS

- In every combination, biomass % left on the terrain was measured.
- Bulk density and moisture of raw biomass and shredded material were sampled and measured, including oven drying for moisture determination.

COSTS AND INCOMES ESTIMATION, TREATMENT COMPARISON (I)

- Hourly costs ← classical methods (Miyata, 1981). Work time (E_0) = common basis for calculations of harvesting operations direct unit costs for timber o.b. m^3 or biomass green tonne.
- As the methods and top diameters could influence both the quantity produced and the production costs of biomass and roundwood for different destinations, the basis for the economic comparison among treatments was the per hectare balance (incomes minus costs)
- Transport costs ← 12.7 €•green $tonne^{-1}$ for shredded biomass and 9.0 €•green $tonne^{-1}$ for timber (good access conditions and short transport distances - 30 km). As neutral to the final balance, no stumpage price was considered for timber or biomass. 15% of indirect and relocation cost + 12.5 % of contractor profits were added to the direct estimated costs.

MATERIAL AND METHODS (V): COST AND INCOME ESTIMATIONS

COSTS AND INCOMES ESTIMATION, TREATMENT COMPARISON (II)

- The incomes were estimated by knowing the different round wood and biomass production per hectare and the different distribution among final uses for the considered top diameters
- As reference market prices, the following values were adopted: 30 €/green tonne in the mill gate for the pulpwood (actually utilized for particleboard), 50 €/gren tonne in the case of other round wood destinations – sawn timber for pallets, poles for fencing – and 42 €/green tonne in the case of shredded biomass.

RESULTS AND DISCUSSION: BIOMASS AND ROUNDWOOD PRODUCTION

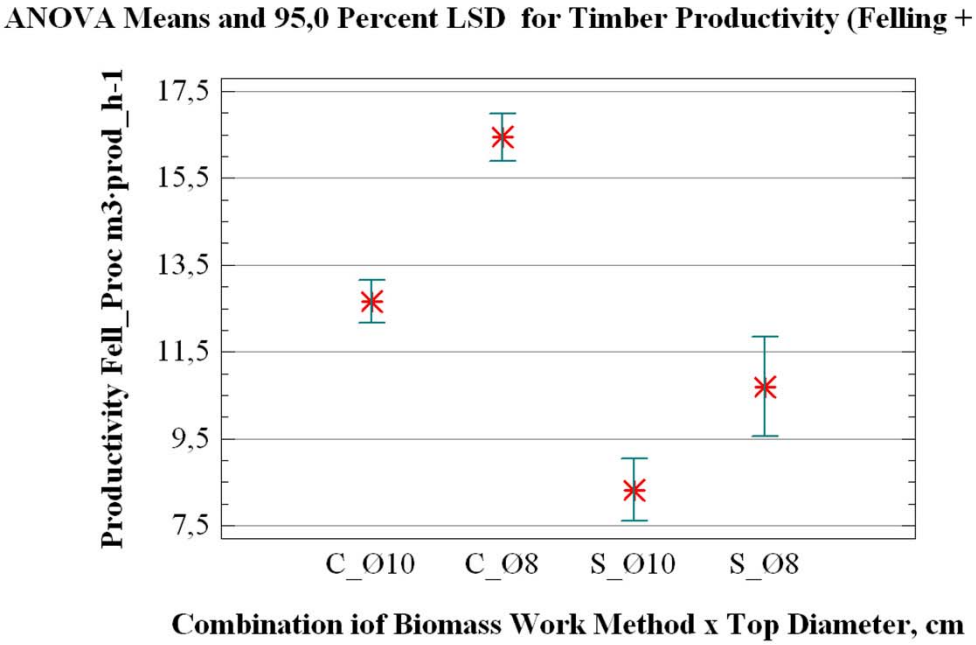
- **Thinning from below**, initial aver. dbh 19.8 cm, basal area 42.5 $m^2 \cdot ha^{-1}$. 470 out of the initial 1,251 $trees \cdot ha^{-1}$ removed (**24 % of initial basal area**)
- The **differences among treatments regarding the residuals amount left on the terrain were not statistically significant**, being the average reduced (925 $kg \cdot ha^{-1}$, 3.9% of the biomass average removal).
- The biomass and wood production for the different treatments top diameters were significantly different, as shown in the Table:

Yield (per hectare)		
Top diameter, cm	Roundwood (o.b. m^3)	Biomass (green tonne, 53.1% moisture, humid basis)
Ø8	42.1	18.6
Ø10	33.2	32.6

RESULTS AND DISCUSSION: WOOD FELLING AND PROCESSING PRODUCTIVITY

Significant differences in productivities among the four combinations “top diameter x bunching method”

Biomass Work Method (S/C)x Top Ø, cm	Count	Mean	Homogeneous Groups			
S_Ø10	30	8.32	X			
S_Ø8	12	10.70		X		
C_Ø10	16	12.66			X	
C_Ø8	52	16.44				X



RESULTS AND DISCUSSION: WOOD FORWARDING PRODUCTIVITY

No significant differences in productivities were found depending on the combinations “top diameter x bunching method”

The following productivity equations correspond, respectively, to plain (0%) and undulate (11%) terrain.

$$\mathbf{Prod(m^3 \cdot E_0 h^{-1}) = [3{,}600 \cdot P(m^3)] / \{933 + 1.52 \cdot P(m^3) / [R(m^3 \cdot ha^{-1}) \cdot S(m) \cdot 10^{-4}] + 1.39 \cdot 2 \cdot HaulingDist(m)\}}$$

$$\mathbf{Prod(m^3 \cdot E_0 h^{-1}) = [3{,}600 \cdot P(m^3)] / \{1{,}097 + 1.97 \cdot P(m^3) / [R(m^3 \cdot ha^{-1}) \cdot S(m) \cdot 10^{-4}] + 1.87 \cdot 2 \cdot HaulingDist(m)\}}$$

Where HaulingDist, m = average distance driven during the off-road transport, half the whole empty and loaded cycle distance; P = Payload(m^3); R = WoodRemoval ($m^3 \cdot ha^{-1}$); S =·StripRoadSeparation (m)

RESULTS AND DISCUSSION: BIOMASS BULLDOZING PRODUCTIVITY

• In the **method "C"** (branches and tops left on the strip road center), **a bulldozer bunched the residual biomass**. **No statistically significant differences** were found between the productivities in plain or undulate terrain, or **between the productivities where the top diameter was 10 cm or 8 cm**.

• The **average productivity 28.6 green tonnes·E_0 hour^{-1}**, was adopted as reference. Density of bulldozed residuals = 149 kg·loose m^{-3} –124 when piled by the harvesting head - moisture content was the same, 53.1% over humid basis.

RESULTS AND DISCUSSION: BIOMASS FORWARDING PRODUCTIVITY

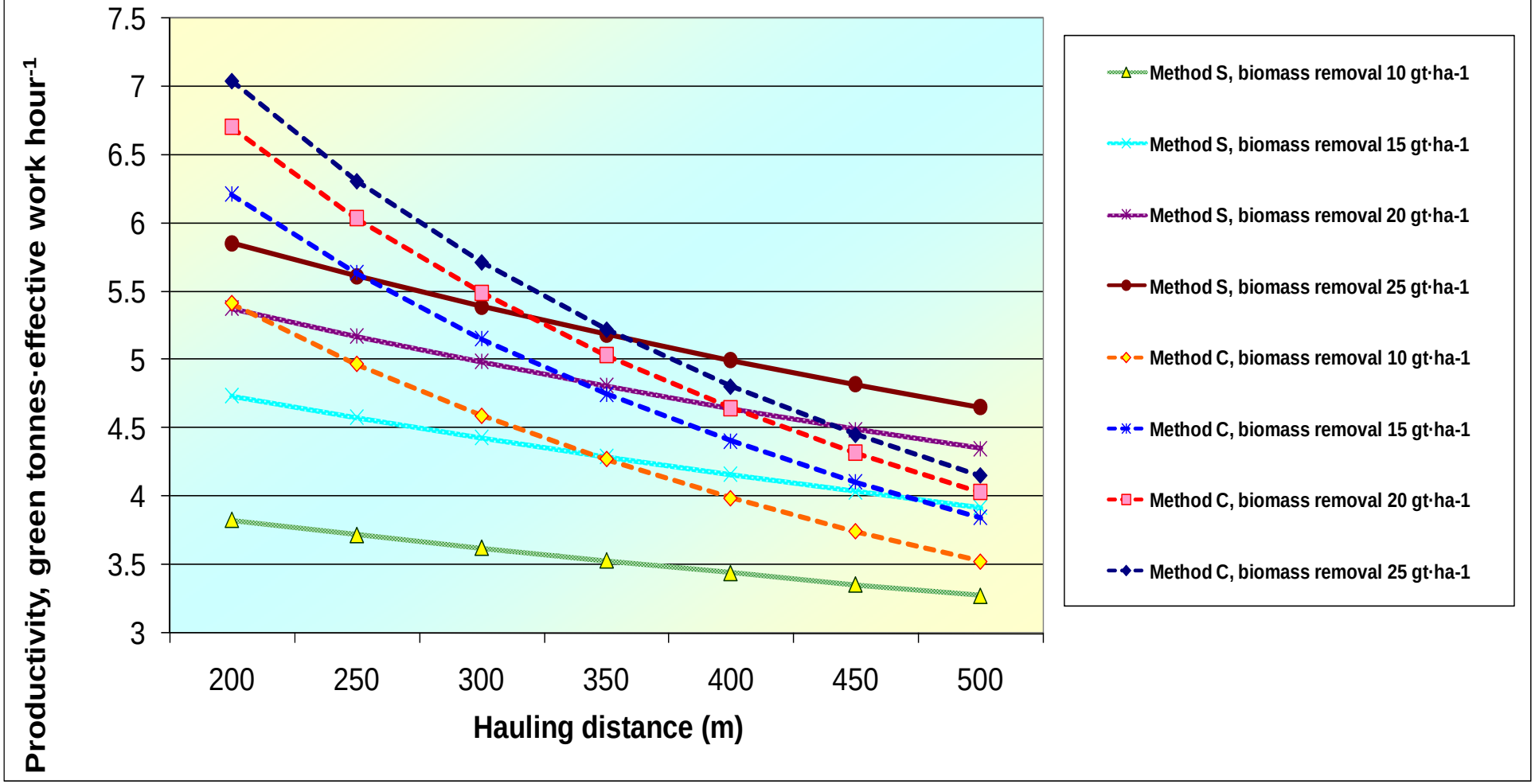
• The **productive times were significantly shorter for the method "C"**, because of the bigger degree of biomass concentration and greater biomass density after its bulldozing.
• After variables transformation and simplification, the following **productivity equations** correspond to biomass management methods S and C.

$$\mathbf{Prod(t \cdot E_0 hour^{-1}) = [3{,}600 \cdot BP(t)] / \{1{,}095.6 + 9.5 \cdot BP(t) / [BR(t \cdot ha^{-1}) \cdot S(m) \cdot 10^{-4}] + 0.99 \cdot 2 \cdot HaulingDist\ (m)\}}$$

$$\mathbf{Prod(t \cdot E_0 hour^{-1}) = [3{,}600 \cdot BP(t)] / \{771{,}9 + 4.48 \cdot BP(t) / [BR(t \cdot ha^{-1}) \cdot S(m) \cdot 10^{-4}] + 2.67 \cdot 2 \cdot HaulingDist\ (m)\}}$$

Where all the variables and units are similar to the used for the roundwood, except t (green tones), the biomass payload BP and the biomass removals BR, both expressed also in green tonnes per load or per hectare. The productivity is represented in next Figure

Thinning residual biomass forwarding productivity for a forwarder payload of 3.75 green tonnes (Method S, branches and tops piled along striproads sides with harvester) or 4.5 g.t. (Method C, branches and tops bulldozed) and striproad separation = 17.5 m



RESULTS AND DISCUSSION: BIOMASS SHREDDING PRODUCTIVITY

Average value = 140.4 loose m^3· E_0 $hour^{-1}$ = **36.5 green tonnes·E_0 $hour^{-1}$**.

High percentage of machine stops because of the extra heating.

No statistically significant differences between shredding biomass from the different top diameters or the different biomass management studied systems.

Average shredded biomass density = 260 kg·loose m^{-3}, moisture content = 51.2 % (humid basis).

RESULTS AND DISCUSSION: COST ESTIMATION

		Alternative (Biomass Management method x Top Diameter)							
		SØ10		SØ8		CØ10		CØ8	
Product	**Operation**	**Prod, $m^3 \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot m^{-3}$**	**Prod, $m^3 \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot m^{-3}$**	**Prod, $m^3 \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot m^{-3}$**	**Prod, $m^3 \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot m^{-3}$**
Round wood	**Felling & Processing**	3.93	16.83	5.42	12.20	7.61	8.69	9.77	6.77
	Forwarding	17.58	2.57	17.58	2.57	17.58	2.57	17.58	2.57
	Transport	------	9.00	------	9.00	------	9.00	------	9.00
	TOTAL	------	**28.40**	------	**23.77**	------	**20.26**	------	**18.34**
Product	**Operation**	**Prod, $t \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot t^{-1}$**	**Prod, $t \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot t^{-1}$**	**Prod, $t \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot t^{-1}$**	**Prod, $t \cdot E_0 h^{-1}$**	**Unit cost, $€ \cdot t^{-1}$**
Shredded biomass	**Bunching w/bulldozer**	------	-----	------	------	28.63	1.33	28.63	1.33
	Forwarding	4.71	11.22	4.71	11.22	6.22	8.50	6.22	8.50
	Shredding	36.51	3.35	36.51	3.35	36.51	3.35	36.51	3.35
	Transport	------	12.70	------	12.70	------	12.70	------	12.70
	TOTAL	------	**27.27**	------	**27.27**	------	**25.88**	------	**25.88**

RESULTS AND DISCUSSION: COST BALANCE

		Alternative (Biomass Management method x Top Diameter)			
		SØ10	**SØ8**	**CØ10**	**CØ8**
Production ($m^3 \cdot ha^{-1}$ /green tonnes$\cdot ha^{-1}$)	**Roundwood**	33.21	42.16	33.21	42.16
	Biomass	32.60	18.60	32.60	18.60
Unit cost (€$\cdot m^{-3}$ / €$\cdot$green tonne^{-1})	**Roundwood**	34.00	28.02	23.50	21.03
	Biomass	31.50	31.50	29.70	29.70
Cost (C, €$\cdot ha^{-1}$)	**Roundwood**	1,129.10	1,181.31	780.40	886.62
	Biomass	1,026.90	585.90	968.20	552.42
	Roundwood +Biomass	2,156.00	1,767.41	1,748.70	1,439.04
Incomes (I, €$\cdot ha^{-1}$)	**Roundwood**	1,394.82	1,666.58	1,394.82	1,666.58
	Biomass	1,369.20	781.20	1,369.20	781.20
	Roundwood +Biomass	2,703,84	2,447.68	2,764.02	2,447.68
Global Balance: Incomes – Costs (I – C, €$\cdot ha^{-1}$)		**547.84**	**576.91**	**1,015.32**	**905.28**

CONCLUSSIONS

- **Positive economic balance of residuals collection in this kind of delayed thinning on gentle terrain, in any of the tried alternatives.**
- **Better economic result of choosing a greater top diameter and of bunching the residual biomass with a bulldozer with raking front implement if compared to piling it along the strip roads sides using the harvesting head.**
- **Further studies should consider the possible negative environmental effects of removing the residuals, particularly when the medium sized bulldozer is used for bunching them.**
- **Also the influence of the tried bunching methods on the biomass quality and price (because of the probable greater sand content when it has been piled with bulldozer) must be taken into account in future studies to refine the economic evaluation.**

Thank You for your Attention