RESEARCH AND TECHNOLOGIC DEVELOPMENT OF COMPOSTING PROCESSES AND ITS APPLICATION IN THE AGRICULTURE AND FORESTRY SECTORS

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1. ABSTRACT

Three types of compost were prepared using sewage sludge, the organic fraction of municipal solid waste and yard trimming biomass in different volume ratios. These composts were employed in trials with several agronomic and forestry plants and in forest nurseries.

In the case of agronomic plants, compost increased significantly the yield of tomato (+40% of the yield obtained with inorganic fertiliser), strawberry (+17%) and cotton (+25%). Compost treatments also increased the vitamin C content of tomatoes and strawberries.

In the case of forestry plants two groups of trials were carried out. Poplar and eucalyptus were included in the first group. In this group, most compost treatments increased significantly the plant height: up to 25% (with respect to inorganic fertiliser treatment) or 39% (with respect to blank, without fertiliser treatment) in eucalyptus. Holm oak, cork tree, carob tree, wild olive and pinion pine were tested in a second group to try reforestation. These results were more heterogeneous, but. in some trials compost incremented plant survival up to 163 % and the plant height up to 156 % (with respect to blank).

In the forest nurseries trials, composts were mixed with peat. In this case, compost favoured carob tree development and had a bioremediation effect.

2. INTRODUCTION

Society is generating a large amount of various organic residues from diverse sources, some of them with an ascending production. In 1998 Andalusia generated 3,147,394 metric tonnes of MSW (17.4% of the national production). Over 1,490,012 metric tonnes (47.5%), was organic matter. In 1995 the Andalusian sewage sludge production was over 105,000 metric tonnes. The mid-term forecast (year 2005) is that Andalusia will generate 22.6% of the Spanish national production (312,500 metric tonnes), once municipalities of more than 2,000 inhabitants will be integrated into the waters purification network. The volume of vegetal biomass coming from the agricultural, forest and landscaping activity is, as it is known, very high, and with little profit. The elimination of these residues by dumping or incineration can create environmental problems, and supposes an important public cost. On the other hand, fertility loss, soil erosion, and water contamination by nitrates of agricultural origin, implies the necessity to recycle those organic raw materials. With the double objective of recycling these leftovers and to solve the environmental consequences of their elimination, the Environmental Ministry of the Andalusian Regional Government initiated two years ago a research and development project of co-composting and agricultural and forest use of these composts.

3. MATERIALS AND METHODS

Municipal organic residues that have a remarkable volume production were used in the compost processing. A number of cultures and species in general used in the Mediterranean countries were selected to test compost applications.

3.1 Compost processing

The method used for the compost processing was the "windrow" method with periodic turnings every 10-15 days. Three types of composts were processed combining the organic fraction of MSW, sewage sludge and yard trimmings in the proportions shown in Table 1.

Compost type	Volume		
	Sewage sludge	OFMSW	Yard trimming biomass
A	1	0	3
B	0	1	1.5
C	1	1	2

Table 1. Volume ratios of raw materials

Biomass was chipped into particles between 2 and 15 cm before the raw materials mixture was made. Piles 2.5 metres high by 5.5 metres wide were prepared. Weekly measurements of the temperature were made during the two months of the fermentation process. One additional month was needed to mature the compost and finish its stabilisation. Finally, the compost was sifted with a 24 mm vibratory sieve.

3.2 Compost uses

The three types of compost were applied in the agricultural and forest trials to verify their validity as an organic fertiliser. A total of 28 trials were set up on a 34.5 ha plot, as indicated in Table 2.

Trial Groups	N. of tests	Trial surface (ha)	Total surface (ha)	Province
Agronomic plants	9	1.2 – 2.4	19.5	Cadiz, Huelva, Seville
Forest cultures	3	0.4 – 0.9	2.0	Huelva, Granada
Reforestation	13	1.0	13.0	Seville, Cadiz
Forest nurseries	3	-	-	Seville, Cadiz

Table 2. Number, surface area and location of trials

3.2.a. Agricultural cultures

Trials were located in Western Andalusia. Cultures of regional importance, on different types of soil were selected. In this way an ample group of agricultural practices was defined (Table 3).

Culture	Texture	OM %	pH	Conven-tional fertiliser.	Kg/ha	Compost	Tm/ha	Irriga-tion
Cotton	Loam	1.8	8.3	8-15-15	700	A, B, C	5, 10	Yes
Rice	Silt Loam	0.8	8.0	25-8-0	500	A, B, C	11, 22, 44	Yes
Strawberry	Sand	1.3	6.1	Hen dung	13500	A	6, 9, 12	Yes
Maize (1)	Loamy Sand	1.4	9.0	15-15-15	700	A, B, C	3, 6	Yes
Maize (2)	Loam	1.0	8.4	8-15-15	800	A, B, C	4, 8	Yes
Sugar beet	Sandy Loam	2.0	8.1	8-24-8	600	A, B, C	4, 8	No
Tomato	Sand	0.8	8.5	15-15-15	500	A, B, C	5, 10	Yes
Hard Wheat	Loamy Sand	0.5	8.6	9-14-9	270	A, B, C	3, 6	No
Grapevine	Silt Loam	1.3	8.3	15-15-15	335	A, B, C	6, 12	No

Table 3. Agricultural trials characteristics (1) Late sowing (2) Early sowing

The effects that the different compost treatments had on harvest production and quality were measured and compared with the corresponding values obtained with the conventional fertiliser and, in some cases, also those obtained without fertiliser (or blank) during the 1998-1999 campaign. For each culture, a completely randomised block with 3 replicates per compost type and dose was used. Results were analysed by One way ANOVA ($p<0.05$) and DUNCAN test was used for mean multiple comparisons. Quality parameters and heavy metals were determined in a composed sample for each treatment.

3.2.b. Forest cultures

The forest cultures that were selected in Andalusia had a goal of direct profits (wood and pulp). Two eucalyptus plots and one poplar were selected. Each culture received the three types of compost in three doses (8,18,26 l/tree) distributed in two superficial applications, as well as a treatment without fertiliser (or blank) and another one with conventional chemical fertiliser (Table 4).

Culture	Texture	OM %	pH	Conventional fertiliser	g/plant
Eucalyptus globules	Sandy Loam	1.1	5.0	9-18-27	200
Eucalyptus globules	Loamy Sand	0.5	5.5	15-15-15	250
Populus x canadensis	Sandy Loam	1.2	8.8	Urea	200

Table 4. Trials with forest plants

The parameters studied were survival, vegetative status and plant height. Each parameter was measured 4 times (June 1998; Nov. 1998; June 1999; Nov. 1999). survival, vegetative state and growth (in height). For each culture, a completely randomised block with 6 (eucalyptus) and 4 (poplar) replicates per compost type and dose was used. Results were analysed by multifactor ANOVA ($p<0.05$) and DUNCAN test was used for mean multiple comparisons.

3.2.c. Reforestation activities

Native forest species of the Mediterranean forest were selected for the reforestation trials with an indirect (conservation and vegetation restoration) profit goal: pinion pine (Pinus pinea), cork oak (Quercus suber), oak (Quercus ilex) and carob tree (Ceratonia siliqua). Each one received the three types of compost in three different doses (4,7,10 l/tree) as well as a treatment without fertiliser and a chemical fertiliser tablet of slow release (48 gr. 4-14-14). Compost application was made once, mixing it with the soil of the same hole at the time it was planted (Table 5).

Species	Texture	OM %	pH
Pinus pinea & Quercus ilex	Sand	1.4	5.5
Quercus suber	Loamy Sand	2.6	5.4
Pinus pinea	Sand	0.5	6.4
Quercus ilex & Quercus suber	Sandy Loam	2.3	6.9
Quercus ilex	Sandy Loam	1.6	6.5
Ceratonia siliqua & Quercus ilex	Sandy Loam	2.6	8.0
Ceratonia siliqua & Quercus ilex	Loamy Sand	0.7	8.3
Ceratonia siliqua & Quercus ilex	Loam	0.9	8.4

Table 5. Reforestation trials

Three measurements were taken in 1999: one after planting, one before summer and one post-summer. These registered the height of the plants and the diameter at the base of the stem. In each trial a completely randomised block with 10 replicates per compost type and dose was used. The plantation frame was 3x3 m. Survival and growth were separately analysed. In survival a contingency analysis and another one of simple correspondences were made. These were divided in two, one for pre-summer survival and another one for post-summer survival. Growth results were analysed by multifactorial ANOVA ($p<0.05$), noting height or diameter increases. tuckey and scheffe multiple comparisons tests were used. in the parcels where they were not fulfilled anova postulates, a non-parametric test kruskal - wallis analysis of the variance had to be made as an alternative.

3.2.d. forest nurseries

Various ratios compost/peat (table 6) were used as substrates in plugs containers. Chosen plants were: carob tree (Ceratonia siliqua), wild olive tree (Olea europaea), holm oak (Quercus ilex).

Species	Propag.	Compost	%(1)
Ceratonia siliqua	Sowing	A	10, 25, 40
Ceratonia siliqua	Sowing	A,B,C	20, 40
Olea europaea var. sylvestris	Trasplant	A,B,C	20, 40
Holm oak	Sowing	A,B,C	20, 40

Table 6 Forest nurseries trials
(1) % compost in volume

Growth was measured by registering root collar diameter and shoot height of the plant. For each trial a completely randomised block with 4 replicates per mixture type compost/peat was used. Results were analysed by One way ANOVA ($p<0.05$) and DUNCAN test was used for mean multiple comparisons.

4. RESULTS AND DISCUSSION

4.1. Compost characteristics

The characteristics of the composts prepared are shown in Table 7. Compost "A" is richer in nutrients than others compost of similar nature (Bures, S. 1997), mainly in nitrogen, potassium and magnesium. Compost "B" has high potassium content (Lopez, R. et al., 1995). The three compost, specially B and C have high salinity (Elect. Cond.). Table 7 shows the analysed fertility parameters.

Parameter	Compost type		
	A	B	C
Moisture content (%)	21.9	13.2	25.3
Density (g/ml)	0.47	0.62	0.71
Organic matter (%)	43.7	20.0	35.6
Water holding capacity (%)	89.0	140.4	69.3
Electrical conductivity (µS/cm)	4,850	6,460	6,580
C.E.C. (meq/100 g)	51.9	55.0	44.8
pH	7.6	7.7	7.2
C/N	16.9	17.1	16.6
Nitrogen kjeldahl (%)	1.50	0.68	1.24
Phosphorus total (µg/g)	1,820	2,360	2,730
Potassium (µg/g)	6,900	6,900	5,800
Calcium (µg/g)	41,900	12,500	15,400
Magnesium (µg/g)	4,600	3,600	4,700
Manganese (µg/g)	255	229	286
Boron (µg/g)	6.6	7.9	7.7
Iron (µg/g)	11,600	8,860	11,800

Table 7: Analysis of Compost

4.2. Compost uses

4.2.a. Agronomic plants

In trials with irrigation most of the compost treatments increased the yield over the corresponding mineral fertilisers treatments (table 8). Best results were obtained for lower doses of compost "A" and highest doses of compost "B" and "C". An economic evaluation was also out to establish the yield threshold of these applications.

Culture	Fertiliser [1]	Increments %	Gross benefit increment %
Cotton	8-15-15	-	-
	Compost A-5	+ 2	-
	Compost A-10	+ 25	+ 31
	Compost B-5	- 11	-
	Compost B-10	+ 23	+ 29
	Compost C-5	+ 9	+ 9
	Compost C-10	+ 22	+ 25
Strawberry	Manure	-	-
	Compost A-6	+ 17	+ 50
	Compost A-9	+ 13	+ 31
	Compost A-12	+ 2	-
Tomato	15-15-15	-	-
	Compost A-5	+ 42	+ 76
	Compost A-10	- 5	-
	Compost B-5	+ 16	-
	Compost B-10	+ 40	+ 62
	Compost C-5	+ 6	-
	Compost C-10	+ 13	-

Table 8. Agricultural results with statistical significance< (1) Number that accompany letters A, B and C shows dose in Tm/ha

The cotton test reached a high statistical significance ($p<1\%$). . All three compost types applied at the rate of 10 Tm/ha increased production more than 20%. Also in strawberry and grapevine caused significant differences ($p<5\%$)
Plant shoot height (H) and root collar diameter (RCD) data were registered. Preliminary results obtained after statistical analyses were very satisfactory ($p<1\%$). Vegetative state of carob tree and wild olive trees plants improved remarkably, both in greenness and in vigour. Carob tree plants with compost did not present symptoms of fungi attack. In this species, growth increases over blank were up to 126% in shoot height and 23% in root collar diameter (table 12).

Species	Measurement	Compost type			Dose (% mixture)	Increments (%)
		A	B	C		
Ceratonia siliqua	H (cm)			X	40	126
	RCD (mm)			X	40	23
Olea europaea var. sylvestris	H (cm)			X	40	112
	RCD (mm)			X	40	30
Quercus ilex	H (cm)			X	40	7
	RCD (mm)		X		20	10

Table 12. Growth results in forest nurseries

4.3. Control of environmental effects

Heavy metals content and E. coli and Salmonella presence in the three types of compost were inferior to the established legal limit for its agricultural use. They also were under ecotoxicology tests, verifying that it did not affect the microbial activity of the ground or the activity of the Eisenia foetida worm. Neither germination nor vegetal growths were affected, and fitotoxicity symptoms did not appear either. Fertility parameters and heavy metal contents in the grounds that received compost were also analysed and it was found these to be below the established legal level. Heavy metal concentration in products harvested from the plants that received compost did not surpassed heavy metal concentration in blank plants. Most toxic (cadmium, lead, chromium and mercury) were below 1 ppm. of dry matter. Paradoxicalally cadmium and chromium higher concentrations were found in inorganic fertilisers (used as blank in agricultural trials) than in compost used. Analytical controls are summarised in table 13.

Samples	Heavy Metals	Microbiology	Organic pollutants
Raw materials	X	X	X
Compost	X	X	X
Soils	X		
Crops	X		
Inorganic fertiliser	X		

Table 13. Analytical controls

5. CONCLUSIONS

5.1. Findings

Under Andalusia climatic conditions of campaign 1998-99, best results due to compost applications were obtained with fast growing forest species (eucalyptus, poplar, carob tree), as much in cultures and reforestation like in nurseries.

In forest cultures, growth results observed in height during those two years showed the possibilities of the use of compost. All three plots showed a positive effect up to 39 % in the eucalyptus-loamy with C3. Soil nature and its influence on the washing away of nutrients, along with the content in compost fertilising elements, could explain the observed growth behaviour in these different treatments. In reforestation, compost only improved rooting in a way worth noting in the sandiest soil (B10 had an 163 % more of survival than blank). Nevertheless, it also gave positive results in the parcels that registered lower drought, which is indicative that in humid sites its beneficial effect would be more notable. In growth, plants fertilised with compost underwent a very remarkable increase compared to the unfertilised ones. This result could be attributed to compost nitrogen abundance and the improvement that it produces in the soil water retention capacity. In forest nurseries compost A and C mixed with actual peat substrates solved carob tree and wild olive trees development problems and had a bioremediation effect

The agricultural irrigated trials showed a positive tendency although it would be precise to fit doses for each type of culture and area since ups and downs were observed. Water contributions were the limiting factor in some reforestation and dry farming parcels and for this reason significant correlation did not appear between soil fertility parameters and the production or plant growth increases.

5.2. Implications

In forest cultures, if the tendency of growth in the plants with compost, until now observed, would remain, the technical viability would be reinforced by the profitability that would be reached with a produced wood increment. In reforestation, soil type, water retention capacity, compost salinity and the way the compost-soil mixture was incorporated influenced the survival of the plant. For that reason the incorporation of compost into plantations holes would be useful in very sandy soils, since addition of compost would improve its hydric properties. Nevertheless in soils with more loam or/and clay content this effect would be diminished and the salinity of the compost could have a negative effect in drought conditions, due to the appearance of osmotic effects. In these cases mixture incorporation would have to be made superficially, where it could help to improve plant establishment after the first summer. Regarding compost use profitability it is now difficult to evaluate the benefit of this amendment in protective reforestation. It would be necessary to study its effect in the mid term, but probably it will depend on the mechanising distribution possibility, and of the compost subsidising option.

It would be also recommendable to increase biomass volume ratio in the compost raw materials mixture in order to help to recreate the soil in those reforestation-poor-soils. It would be also recommendable in nurseries with the objective to try to replace the actual substratum instead of just complementing it. In these forestry nurseries it would be needed to make more experiences to adapt compost doses for other nursery species of actual majority production in Andalusian region. At actual compost prices, the most profitable agricultural use would be in intensive cultures, where the agriculturist obtains a high economic return. Distance from the crop plot to the composting plant would influence profitability. For intensive cultures longer distances could be covered. Anyway, it would be precise to fit compost doses because the final objective would be to offer to the final consumer of compost, a manual on its use. In cultures with lower economic return, according to the initial records, it would be interesting to consider as well as in reforestation a policy of subventions to extend the use of these products. It was clearly defined the need to make a demonstration trial network with those plots and new experiences in gardening, landscaping, nurseries, olive groves and fruit cultures after the dissemination phase of this project. It would be also necessary to make an effort to standardize composts that are produced and therefore to establish their official classification according to their standards. It was obvious that the improvement of the compost products would be possible by demand of informed and advised consumers.

6. ACKNOWLEDGEMENTS

The authors wish to express their gratitude to all those people and organisations that collaborated from the beginning and until the accomplishment of this project, and very specially to the owner of the plots and to Juan Gervilla, Francisco Tapia, Norberto Ruiz, Luis Sobrino, Jose M. Trillo, F.Javier Salas, Rafael Lopez, Catalina Alarcón, Ana Cruz, Federico Ruiz, Javier Verano, Rafael Cuesta, Jose Mª Gómez, Germán Reviriego, José de Castro, Emilio Martínez., José Palma, Alberto Fraguas, Carlos Ibero, Ignacio Torres, Juan Revilla y Marcelino Bilbao.

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