Effect of C/N ratio on the composting of vineyard pruning residues

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Summary

We investigated the composting process of fresh, chopped vineyard pruning residues (DM 35 %) at various initial C:N ratios of 60:1 (original), 52:1, 40:1, and 29:1 for 133 days in 250 litre rotting boxes with self-aeration. Urea (46 % N) was added as nitrogen supplement to attain a desirable C:N ratio. The composts were turned after 14, 23, 30, 38, 52, 65, 79, 93, 111, 122, and 133 days.

The degradation of organic matter was between 19 % (at the initial C:N ratio of 60:1) and 39 % (at the initial C:N ration of 29:1) within 133 days, and the resulting C:N ratios were between 46:1 and 18:1. The compost maturity was evaluated by a self-heating test, C:N ratio, NH_4^+/NO_3^+ ratio, NH_4^+-N content, E665, and germination index.

A supplementation of about 1.5 litres water per kg fresh material was necessary to stabilize the biological activity of the composting process during the first 40 to 60 days. Nitrogen supplementation with urea, or another nitrogen source, can accelerate the rotting process, but the higher the urea supplementation, the higher the losses of nitrogen by ammonia evaporation. The optimum urea nitrogen supplementation was in the range of 2 g kg^{-1} dry matter.

The parameters of C:N ratio, NH_4^+/NO_3^+ ratio and E665 were no clear criteria for compost maturity, because they depend on the type of material. The simple germination test could be used to determine the compost maturity in the composting of vineyard pruning residues. Based on the results, a rotting period of at least 80 days was proposed for chopped vineyard pruning residues.

Keywords: vineyard pruning residues, compost, C:N ratio, maturity

Zusammenfassung

Einfluss des C/N Verhältnisses auf die Kompostierung von Rebschnitt

Der Kompostierungsverlauf von frischem, gehäckseltem Rebschnitt (TM 35 %) mit unterschiedlichen C:N-Verhältnissen von 60:1 (Original), 52:1, 40:1 wurde während 133 Tagen in 250 Liter Rottebehältern mit Eigenbelüftung untersucht. Zur Stickstoffergänzung wurde Harnstoff (N-Gehalt 46 %) zugegeben. Nach 14, 23, 30, 38, 52, 65, 79, 93, 111, 122 und 133 Tagen wurde der Kompost umgesetzt.

Der Abbau der organischen Substanz lag zwischen 19 % (C/N-Verhältnis zu Beginn 60:1) und 39 % (C:N-Verhältnis zu Beginn 29:1) und das C/N-Verhältnis zum Ende zwischen 46:1 bzw. 18:1. Der Reifegrad wurde bewertet anhand eines Selbsterhitzungstests, dem C/N-Verhältnis, dem NH_4^+/NO_3^+-N-Verhältnis, dem E665-Wert und dem Keimindex.

Zur Aufrechterhaltung der biologischen Aktivität während der ersten 40 bis 60 Tage ist eine Zugabe von etwa 1,5 Liter Wasser je kg Rebschnitt notwendig. Eine Stickstoffzugabe, mit Harnstoff oder anderen Stickstoffquellen, kann den Rotteprozess beschleunigen, führt aber zu höheren Stickstoffverlusten durch abgasendes Ammoniak. Die optimale Stickstoffzugabe liegt bei 2 g kg^{-1} Rebschnitt.

Die Parameter C:N-Verhältnis, NH_4^+/NO_3^+-Verhältnis und E665-Wert geben keine klare Aussage über die Kompostreife, da sie vom Rottematerial abhängen. Ein einfacher Keimtest ist ausreichend zur Bestimmung des Rottegrades von kompostiertem Rebschnitt. Auf der Grundlage dieses Ergebnisses wird für Rebschnitt eine Rottezeit von 80 Tagen vorgeschlagen.

Schlüsselworte: Rebschnitt, Kompost, C:N-Verhältnis, Reifegrad

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1 Introduction

In order to select fruiting wood, maintain vine shape and form, and regulate the number of buds retained per vine for current and sustainable yield and quality of grapes, an annual dormant pruning practice is necessary. The amount of vineyard pruning residues was estimated in a range of 1 to 7.5 t ha^{-1} a^{-1}, at an average of 2 to 4 t (Fischer, 1982; Fischer, 1984; Sanchez et al., 2002). With an amount of 1.1 t ODM (organic dry matter), 8 kg N, 1.2 kg P, 5.6 kg K ha^{-1} a^{-1} and high levels of microelements required by crops. To date, there appears to be a relatively small number of utilisation options available for pruning residues. The principal options known were: fuel, industrial raw material (paper pulp, fibre boards), mushroom substrate (Chalaux et al., 1995) and direct turn-over into the vineyard as mulch after shredding or after composting. Mulching of the pruning residues between the rows in the vineyard is the common procedure in Europe and America, but it is no alternative in arid oasis agro-systems with irrigation farming. Under arid climate conditions the microbial activity in vineyard soil is very low and the pruning residues mulched are unlikely to be degraded. The conventional fertilizer regime in vineyards in China is to distribute organic fertilizer into a furrow at a depth of about 50 cm near the grapevine trunk, where available soil moisture and fertilizers can be used by the root system. The same procedure is not suitable for fresh pruning residues because of the lack of oxygen in the soil, the high lignin content of 49 % (Sanchez et al., 2002), the high C:N ratio of 60 to 89 (Wang et al., 2005; Sanchez et al., 2002) and the phytotoxicity of fatty acids during the early stages of decomposition processes. More than 60 % of the wine grape-growing areas in China are located in the arid and semi-arid areas (Wang, 2005). The vineyards in these areas are inherently characterized by low soil organic matter content with less than 10 g kg^{-1}. The arid climate and the intensive, humus-consuming wine grape growing require each kind of organic fertilizer, which is available and acceptable under the view point of the price and the content of heavy metal and hazardous organic components. The high initial C:N ratio will cause a slower beginning of the process and the required composting time to be longer than usual (Tuomela et al., 2000), which requires the supplement of a nitrogen source, such as manure, sewage sludge, urea or other waste materials rich in nitrogen, to produce compost under economical conditions. However, the effect of carbon to nitrogen ratio on composting of vineyard pruning residues has not been well understood, even though some farmers use the chopped material in mixtures with pomace, green waste or agricultural waste. Therefore, the present study aimed to assess the effects of C to N ratio on composting of vineyard pruning residues in 250 litre rotting boxes, as described in this paper, and was amended by trials in heaps under practical conditions.

2 Material and methods

2.1 *Composting in rotting boxes*

Vineyard pruning residues from a 2,000 ha vineyard (Huang Yanghe Farm; near Wuwei in Gansu province in the northwest of China; desert climate with precipitation of <200 mm a^{-1}) were cut at the end of October. The pruning residues were chopped mechanically with a commercial agricultural machine; the resulting average size was 7.5 mm.

Heat insulated wooden rotting boxes (50 × 50 × 100 cm; 50 mm insulation) were constructed. A plastic sheet with 10 holes (Diameter: 5 mm, spacing 10 to 12 cm) covered the material on the top of box, and then allowed simultaneous gas exchange or water evaporation reduction. The boxes were placed indoors at an average ambient temperature of approximately 19 °C. Fresh air aerated through the bottom of box, supported by the chimney effect of the warm rotting material. For each rotting box, 70 kg of the fresh vineyard pruning was adjusted with the required amount of nitrogen in the form of urea (N 46 % fertilizer grade), mixed thoroughly and wetted repeatedly to obtain a moisture content of 61 % (w/w). Table 1 shows the supplement of urea and water and the resulting C:N ratios of the mixtures.

Table 1:
Mixtures of vineyard pruning residues and nitrogen and water

Trial	N supplement		Water supplement		Initial C/N
	g kg^{-1}	g kg^{-1} DM	g kg^{-1}	g kg^{-1} DM	
CN 60	0	0	0.64	1.05	60
CN 52	0.63	1.03	0.64	1.05	52
CN 40	2.21	3.62	0.64	1.05	40
CN 29	4.60	7.52	0.64	1.05	29

2.2 *Sampling and Analytical Procedures*

The rotting material was turned to facilitate the aeration, watering , sampling and measurement of mass, volume, and bulk density after 0, 14, 23, 30, 38, 52, 65, 79, 93, 111, 122, and 133 days of composting. Samples (about 100 g each) were taken before watering at each turning of the compost.

2.3 Physical measurements

The temperature during composting was measured daily at a central point in the box.

Wet bulk density (BD) = M_{wet}/V_{wet} (M_{wet} = mass of non-dried material in kg, V_{wet} = volume of the material in m^3).

Mass balance: Mass (%) = $M_t/(M_0$ x 100) (M_t and M_0 are mass of dry matter and N_{Kj} at day t and day 0 of composting, respectively.

2.4 Chemical Analysis

All chemical analysis were made in triplicate and all analysis figures were given on a dry matter basis. Dry matter (DM) content: drying at 105 °C for 12 h (Paredes et al., 2000). Organic matter (OM): loss on ignition at 550 °C for 6 h (Provenzano et al., 2001). Carbon content: calculated on the basis of a C content of polysaccharides of 44.4 % of OM (Haug, 1993). Total N: Kjeldahl method (Benito et al., 2003). NH_4^+-N: steam distillation with magnesium oxide and collected in boric acid (Chung and Wang, 2000). NO_3^--N: analyzed by salicylic-sulphuric acid digestion (Jimenez and Ladha, 1993). The pH and the absorbance at 665 nm (E665) in the filtrates above were measured directly by an Orin 920 ISE pH meter, and an UV/Vis Spectrophotometer, respectively. Elements (P, K, Ca, Mg, Fe, Mn, Cu, Zn, Na, Ba and B, Mo) were analyzed with Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) (Sah and Miller, 1992; Meyer and Keliher, 1992).

2.5 Phytotoxicity and maturity

Seed germination and radicle length tests were performed in germination boxes (11.5 x 11.5 x 4.5 cm, ZAU, China) with selected Chinese cabbage seeds (*Brassica rapa*).

The germination index (GI) for evaluating phytotoxicity was calculated according to the formula of Huang et al. (2001):

GI (%) = G_t x L_t x 100/(G_c x L_c)
G_t = seeds germinated in treatment
G_c = seeds germinated in control
L_t = length of radicle in treatment
L_c = length of radicle in control

Self-heating test: in Dewar vessels (FCQAO, 1994).

3 Results and discussion

3.1 Temperature

The results of the effects of C:N ratio on the composting temperature are shown in Figure 1. After two days of composting, all four treatments reached 50 °C and entered the thermophilic range (>50 °C), indicating the quick establishment of microbial activities associated with respiratory metabolism in the composting boxes. In general, the temperature profile shows that the lower the C:N ratio, the higher the maximum temperature attained and the longer the duration of the thermophilic phase. There were significant differences in the maximum temperature and the length of thermophilic range among the four treatments. The maximum temperature values reached 76 °C (C:N 29), 70 °C (C:N 40), 68 °C (C:N 52) and 65 °C (C:N 60), which appeared after three to four days of composting. The length of the thermophilic phase was 20 days (C:N 29 and 40) and 6 days (C:N 52 and 60), respectively. The periodical short-term drop in temperature was due to the cooling effect caused by the turning and water supplement to the medium. Based on the temperature level and the holding time, the sanitation effect by the temperature in the trials with C:N 29 and 40 should be sufficient.

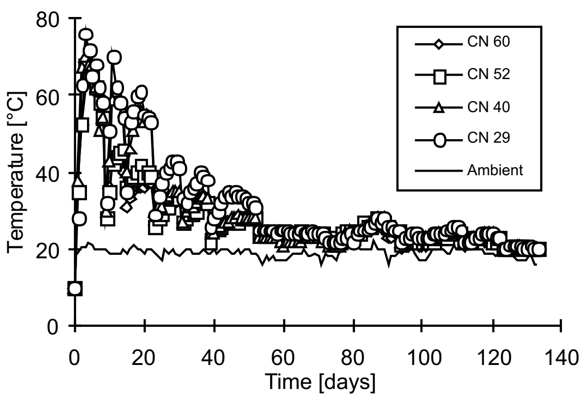

Figure 1:

Temperature during vineyard pruning residues composting at different initial C:N ratios

3.2 Composition and mass balance

The composition of the fresh pruning and of the final compost is given in table 2. The original dry matter content (DM) of the pruning material of 612 g kg^{-1} was too high for biological degradation. To ensure activation of the composting process, water was added at the start and at each turning, if necessary, following the individual impression of a hand probe. The total water supplement was in a range of 1.4 to 1.9 L kg^{-1} fresh material (Figure 2). Because the water evaporation rate was less than the water supplement (0.7 to 1.3 L kg^{-1} fresh material) the dry matter content fell continuously (Figure 3a) without remarkable amount of leachate. During the entire rotting period the water content was high enough for bacterial activity, but possibly too high for fungal growth. The optimal dry matter content for the composting of the pruning residues seems to be in the range of 250 to 300 g kg^{-1}.

Table 2:

Some characteristics of vineyard pruning residue and the compost after 133 days rotting time

Parameter	Units	Raw material	Compost
DM	g kg^{-1}	612	230
OM	g kg^{-1}	975	940
C/N	-	60	35
pH	-	7.4	7.8
EC	mS m^{-1}	1148	728
N (DM)	g kg^{-1}	7.2	11.9
P (DM)	g kg^{-1}	1.1	1.6
K (DM)	g kg^{-1}	5	6.3
Ca (DM)	g kg^{-1}	16.1	21.5
Mg (DM)	g kg^{-1}	1.4	2.1
Bulk density	kg m^{-3}	288	550

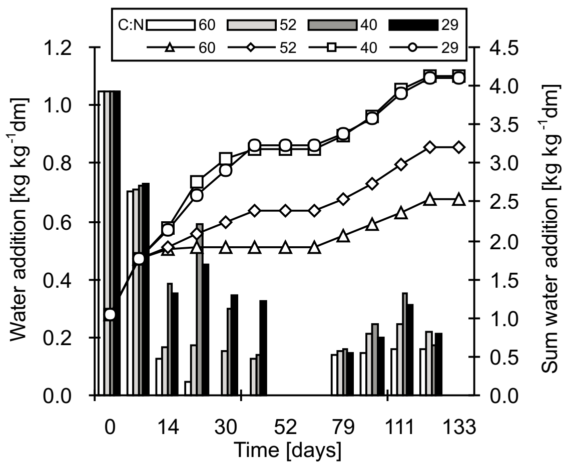

Figure 2:

Water supplement in substrate during vineyard pruning residues composting at different initial C:N ratios

In all treatments, the DM mass declined within the composting period due to a degradation of organic substances (Figure 3b). A notable rapid degradation during the first 30 days, followed by a longer period of slow degradation, was observed. The former is due to the metabolization of most of the easily biodegradable substances during the first stage of the composting process when the temperature and the microbial activity were high. While the latter is likely due to the decomposition of lignin and the formation of humic matter during the maturation period of composting (Wu et al., 1997; Ouatmane et al., 2000; Namkoong et al., 1999, Benito et al., 2003). The total degradation of the dry matter was 39 % (C:N 60), 52 % (C:N 52), 55 % (C:N 40) and 59 % (C:N 29), respectively.

During the whole rotting period the pH-value was in the alkaline range between 7.2 and 8.3, without significant differences between all four trials. The bulk density was in the range of 450 to 550 kg all the time. Changes of the nitrogen during the composting process are presented in Figure 4a. A slight increase of total nitrogen content was observed in all treatments with composting time, due to the losses of organic substance which were higher in relation to the losses of nitrogen. The increase of total nitrogen content was 28 % (C:N 60), 45 % (C:N 52), 44 % (C:N 40) and 53 % (C:N 29), respectively during 133 days of composting. In contrast to total nitrogen content, total nitrogen mass loss followed the same pattern as the DM and OM mass loss (Figure 4b). The total nitrogen mass loss rate of initial mass was 23 % (C:N 60), 31 % (C:N 52), 35 % (C:N 40) and 37 % (C:N 29), respectively. A calculation of the nitrogen losses from the pruning residues and the urea shows that the losses from the urea-N only were 14 % (C:N 52), 41 % (C:N 40) and 49 % (C:N 29), respectively (Table 3).

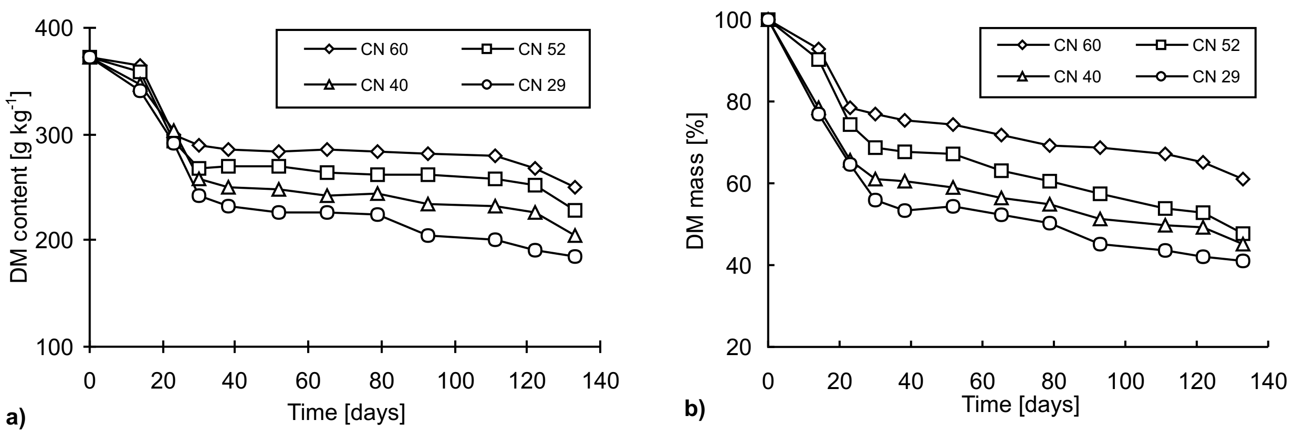

Figure 3:

DM content (a) and DM mass (b) during vineyard pruning residues composting at different initial C:N ratios

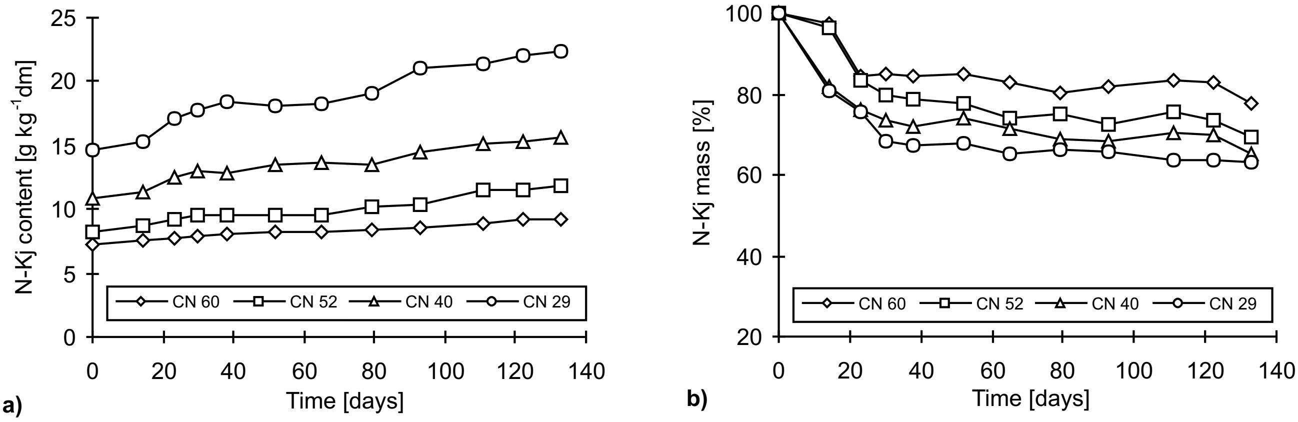

Figure 4:
Total nitrogen content (a) and mass (b) during vineyard pruning residues composting at different initial C:N ratios

Table 3:
Nitrogen balance after 133 days rotting time, calculated on DM basis

Trial	Urea N addition	Sum	Losses total	Losses from pruning*	Losses from urea	Urea-N input minus l losses from urea	
	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	%
CN 60	0	7.2	1.62	1.62	0	0	0
CN 52	1.03	8.23	2.51	1.62	0.89	0.14	14
CN 40	3.62	10.82	3.75	1.62	2.13	1.49	41
CN 29	7.52	14.72	5.47	1.62	3.85	3.66	49

* it is assumed that the N losses from the pruning are the same in all four trials

Due to the ammonification, the NH_4^+-N content for all treatments with urea supplement increased rapidly during the thermophilic phase, whereas the NH_4^+-N content of the pure pruning residues was almost constant (Figure 5a). The high temperatures at a pH level >7 were the main reason for the nitrogen losses and the decrease of the NH_4^+-N content. The NO_3^--N content remained at a low level during the first 30 days of composting (Figure 5b) because of the inhibition of the nitrificant bacteria during the thermophilic phase at temperatures higher than 40 °C (Bernal et al., 1999; Díaz et al., 2002). Thereafter NO_3^--N increased sharply due to nitrification, with a maximum by day 52. Thereafter the NO_3^--N content fell because of denitrification, possibly initiated by the high water content and partially anaerobic zones in the rotting material. The nitrification process started again after day 93.

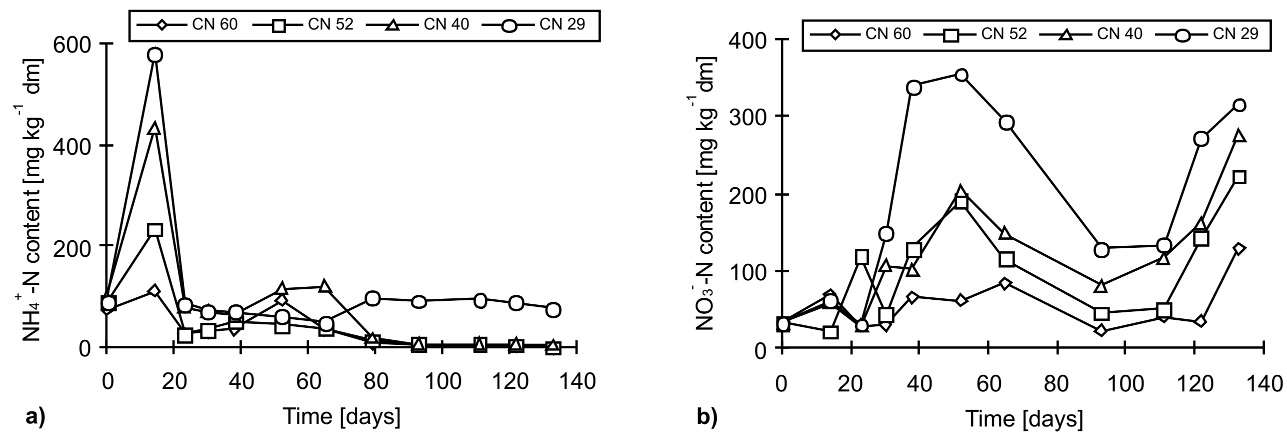

Figure 5:
NH_4^+-N content(a) and NO_3^--N content (b) during vineyard pruning residues composting at different initial C:N ratios

3.3 Compost maturity

Several criteria were used to evaluate the maturity of the compost: the self-heating temperature (a), self-heating test (b), C:N ratio (c), NH_4^+-N content (d), NH_4^+-N/NO_3^--N relation (e), absorbance at 665nm (E665) (f) germination index (g) and a sensory evaluation of colour and smell (h). A FT-IR spectroscopy of the rotting material at the start and after 15, 60 and 120 days showed the changes of the composition, but cannot give an answer about the maturity status of the compost (Wang et al., 2004).

Except for the criteria "C:N ratio" (Figure 6a), all other criteria indicate a mature compost after 0 to 90 days (Table 4). It is concluded that the ratio of NH_4^+-N/NO_3^-–N and the E665 (Figure 6b) do not provide clear and well-defined criteria for this kind of lignin rich waste material. The only possible applicable criteria for evaluating the compost maturity of the vineyard pruning residues, other than a final plant test, could be the self-heating temperature (=biological activity) in combination with the germination test (=root tolerance). Following these criteria, the compost is mature after 65 days (germination index >80; Huang, 2001) even though the C:N ratio is still 23 to 50 (Figure 6a). All easily degradable compounds are metabolized at that time and mainly lignin compounds are left. The germination increased significantly during the following 15 days, but only trials with the C:N ratio of 40 and 29 could reach a germination index of >100 (after 93 days). The colour (dark brown) and the smell (compost, soil) of the rotting material indicate the end of the high biological

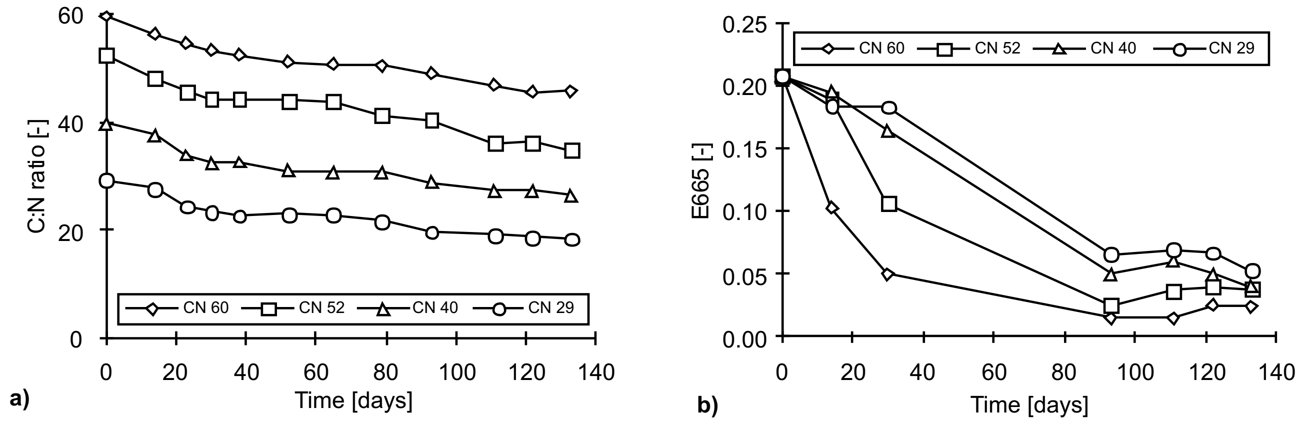

Figure 6:
C:N ratio (a) and E665 value (b) during vineyard pruning residues composting at different initial C:N ratios

Table 4:
Maturity criteria for compost from vineyard pruning residues

Criteria	Reference	Target value	Actual value	Day	Maturity	Figure
selfheating temperature	-	near ambient temperature	<25 °C	53	yes	1
selfheating test	FCQAO, 1994	<30 °C	24-25 °C	133	yes	-
C/N ratio	Bernal et al., 1998b; Iglesia-Jimenez and Perez-Garcia, 1992	<15	18 (C/N 29) 26 (C/N 40) 35 (C/N 52) 46 (C/N 60)	133	no	6a
NH_4^+-N	Zucconi and De Bertoldi, 1987; Paredes et al., 2000	<400 mg kg^{-1}	88 mg kg^{-1}(start)	0	yes	5a
NH_4^+/NO_3^-	Forster et al., 1993; Bernal et al., 1998a; Bernal et al., 1998b	<1	<1	38 (C/N 60) 23 (C/N 52) 30 (C/N 40) 30 (C/N 29)	yes	-
E665	Mathur, 1993; Rajbanshi and Inubushi, 1998	<0.07	<0.07	25 (C/N 60) 60 (C/N 52) 90 (C/N 40) 90 (C/N 29)	yes	6b
germination index	Huang et al., 2001	80-85	>80	65	yes	7
colour	own scheme	dark brown, black	dark brown, black	38	yes	-
smell	own scheme	forest soil, compost, no ammonia	forest soil, compost, no ammonia	30	yes	-

activity after 30 to 38 days and the beginning of the maturing phase with the activity of nitrificant bacteria.

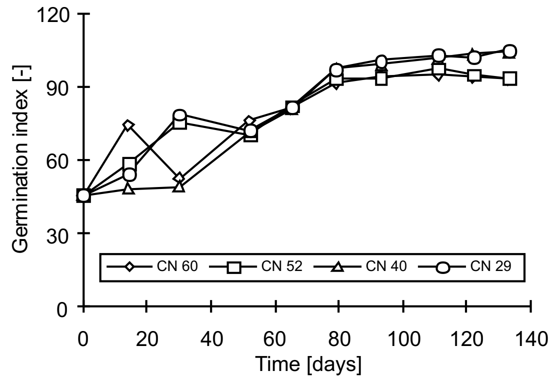

Figure 7:

Germination index during vineyard pruning residues composting at different initial C:N ratios

4 Conclusions

Vineyard pruning residues can be used for compost production after chopping and supplement of water. The size of the chopped material (24 % <4 cm, 56 % 4 to 10 cm; 20 % >10 cm) was sufficient for an intensive rotting process. The continuous supplement of water during the first 40 to 60 days of composting, the high temperature phase, is necessary to stabilize the biological activity. After that time the water supplement should be stopped to reduce the water content by evaporation and to obtain a usable and marketable material. The supplement of about 1.5 L water per kg fresh waste material seems to be optimal. At a resulting dry matter content of about 250 g kg^{-1} after 60 days the rotting material has reached its full water capacity without any water surplus as leakage water. Almost half of the added water should be provided to the chopped pruning residues at the start. The activity of actinomycetes and fungi was possibly limited at a dry matter content of <250 g kg^{-1}.

The supplement of urea at the start results in higher biological activity, measured as temperature, higher degradation of organic matter, measured as losses of dry matter mass, and a higher germination index after 80 days. The disadvantage of the urea supplement is the volatilisation of ammonia, growing with the supplement rate up to 49 %. Under consideration of a high germination index and reduced ammonia nitrogen losses, the optimum urea nitrogen supplement could be in the range of 2 g kg^{-1} dry matter. In practice the nitrogen source can be nitrogen rich waste, waste water or sludge, if available.

As discussed in several publications, maturity tests such as C:N ratio, NH_4/NO_3 ratio and E665 are no clear criteria for compost maturity in general, because they are dependent on the type of material. The simple germination test could be used to determine the compost maturity in the composting of vineyard pruning residues. Based on the results, a rotting period of at least 80 days is proposed for chopped vineyard pruning residues.

The turning frequency of the rotting heaps under practical conditions depends on the climate conditions and the evaporation rate, especially at the surface. Because of the high air pores volume and the stable structure of the material, a turning is necessary only to homogenize the material and to dry the compost for screening and selling. A weekly turning, as described for the trials, is not necessary.

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