INFLUENCE OF ENVIRONMENTAL FACTORS ON THE CARBON DIOXIDE PRODUCTION OF MUSHROOM SUBSTRATE

H. Loeffen, J.C. Bakker
DLO-Institute of Agricultural and Environmental Engineering (imag-dlo)
PO Box 43
6700 AA Wageningen
The Netherlands

Additional index words: mushroom, carbon dioxide, compost, substrate

Abstract

An important characteristic of the mushroom cultivation is the "activity" of substrate. The correlations were determined between climate factors and CO_2 production per phase of seven crops. The CO_2 production was used as a measure for substrate activity. During the vegetative phases high correlations were found between compost temperature, vapour pressure and CO_2 pressure in the compost and average CO_2 production per phase. In all vegetative phases, average temperature, CO_2 pressure and vapour pressure differences between compost and growing room air were highly correlated with the CO_2 production. This correlation was also found for differences in vapour pressure during the second and third flush and for CO_2 pressure differences between compost and growing room air during the first flush. At equal average temperature, vapour pressure and CO_2 pressure in compost, the average CO_2 production per phase during the flushes were higher then during the vegetative phases. This might be caused by a larger exchange area due to an increase in the number and size of fruit bodies. Climate factors which were highly correlated with the CO_2 production can be used to control crops on the basis of the CO_2 production.

1. Introduction

One of the most important characteristics of the mushroom cultivation which influences mushroom production, is the degree in compost activity during cultivation. In general activity in compost is derived from the difference in temperature between compost and growing room air. However, the influence of environmental factors on substrate activity is unknown. As the biological activity of organic material in soils and compost leads to CO_2 production, the carbon dioxide production rate can be used as a possible measure of the substrate activity (Anderson & Domisch, 1972, Wiegant, 1992).

Previously research (Loeffen, 1993) indicated a relationship between carbon dioxide production rate of growing beds and the final yield of mushrooms. This relationship might be used to develop a method to optimize the environmental conditions of mushroom growing rooms. As a first step the effects of climate factors on carbon dioxide production rate has to be known. Besides environmental conditions, cultural practices and hygiene measures remain important factors which influence the yield and quality of mushrooms. This paper describes the relationship between the average climate factors per phase with the average carbon dioxide production rate per phase of seven similar cultivations having different compost qualities.

2. Method

Seven crops (A - G) were grown with full-grown compost of the CNC (The Dutch Mushroom Growers Association) spawned with strain U1 and supplemented with 1 kg Milli Champ 3000 m^2. Compost was covered with a 5 cm layer of casing soil.

2.1 Analyses

The composition of the different compost qualities used for these experiments was analysed at time of filling. The fill weight, moisture content, bulk density, pH and the nitrogen content of the full grown compost were determined (Table 1).

Table 1 - Composition of full grown composts at time of filling

experiment	weight of compost $kg{\bullet}m^{-2}$	moisture content %	bulk density $kg{\bullet}m^{-3}$	pH	NH_4-N
A	87.6	68.0	461	*	*
B	94.6	67.3	498	*	*
C	82.0	64.9	432	8.3	5.4
D	83.2	63.3	438	8.6	5.6
E	89.5	65.2	471	8.5	7.7
F	84.4	67.0	446	8.8	8.3
G	84.4	65.8	444	8.5	6.9

(*) not measured

2.2 Climate set points

Temperature, relative humidity and carbon dioxide concentration were controlled by an over pressure climate system. The set points of the climate factors were equally set up per phase for seven cultivations (Table 2).

Table 2 - Climate set points in compost (comp) and growing room air per phase. T= temperature, RH = relative huminity, CO_2 = CO_2 concentration, A = air circulation

Setpoints		phases						
		vegetative				flushes		
		mycelium	rufling	ventilating	pinheading	first	second	third
T °C	air	24*)	24		18	19	19	20
	comp			18+)				
RH %	air	95	95	95	90	83	83	83
CO_2 ppm	air			800	800	800	800	800
A $m^3 \cdot h^{-1}$		1500	1500	2000	1500	1500	1500	1500

(*) Average temperature of compost and growing room air
(+) Compost temperature

2.3 Measurements

Measurements in the growing room were carried out every five minutes (Figure 1). The temperature of compost, casing soil and growing room air, the carbon dioxide concentration in compost and the growing room air were measured at six places in the growing room (P1-P6). P2 was measured in the front and P4 at the back of the growing bed. The relative humidity was measured above the growing bed at the top, in the middle and the lowest. The air flow, the air pressure, the air temperature, the carbon dioxide concentration and the relative humidity in the air were measured. The carbon dioxide balance of the mushroom growing room was calculated from the measured mass flow of carbon dioxide supplied and discharged through the growing room (ventilated, recirculated and circulated).

2.4 Carbon dioxide balance

From the measurements average values per hour were calculated. These hourly averages were used to calculate the carbon dioxide balance of the growing room (Figure 2). The amount of carbon dioxide accumulated, and discharged by ventilation and leakage was calculated by:

$$Q_{CO_2} = \Phi_{mv} + \Phi_{mL} + \frac{dm_{CO_2}}{dt}$$

Q_{CO_2} = *carbon dioxide production as function of time [kg • h⁻1]*

Φ_{mv} = *mass of carbon dioxide discharged by ventilation [kg • h⁻1]*

Φ_{mL} = *mass of carbon dioxide discharged by leakage [kg • h⁻1]*

$\frac{dm_{CO_2}}{dt}$ = *mass of carbon dioxide accumulated [kg • h⁻1]*

The amount of carbon dioxide exhaled by people in the growing room was calculated using data from practice and literature, and for the total period estimated to about one per cent of the total carbon dioxide produced. On harvesting days during the first and the second flush, however, twenty to thirty percent of the daily carbon dioxide production was estimated as being contributed by people.

The carbon dioxide dissolved in water of compost and casing soil as cause of an decrease in temperature and increase in partial carbon dioxide pressure was calculated. Maximum amounts were about 100g CO_2 m^2 of crop. This amount has a very small effect on the total amount of carbon dioxide produced and is therefore neglected in the carbon dioxide balance.

2.4.1 Ventilation

The amount of air ventilated depends on the sensible and latent load and the environmental conditions of the growing room as by a fan. The amount of carbon dioxide discharged by ventilation was calculated as:

$$\_\Phi_{mv} = ((C_i - C_a) \bullet \Phi_v \bullet \rho_{CO_2} i$$

Φ_{mv} = *mass of carbon dioxide discharged by ventilation [kg_h⁻1]*

C_i = *carbon dioxide concentration of the growing room air [ppm]*

C_a = *carbon dioxide concentration of the ambient air [ppm]*

Φ_v = *ventilation rate [m³_h⁻1]*

$\rho_{CO_2} i$ = *density of the carbon dioxide [kg_m⁻3]*

The total amount of carbon dioxide discharged by ventilation during a period of t=0 till $t=t_1$, and was calculated as:

$$m_v = {}_0\int^{t} 1\, \Phi_{mv}(t) \bullet dt$$

2.4.2 Leakage of carbon dioxide

The leakage air of the growing room was determined by the decay rate method using CO_2 as a tracer gas concentration. The decrease of the carbon dioxide concentration can be described by:

$$c_i(t) = \exp^{(}\Phi_{vL} \bullet \frac{t}{V}) \bullet (c_i(0) - c_a(t)) + c_a(t)$$

$c_i(t)$ = *carbon dioxide concentration of the growing room air at time(t) [ppm]*

Φ_{vL} = *ventilation rate of air by leakage [$m^3 \bullet h^- 1$]*

$c_i(0)$ = *initial carbon dioxide concentration of the growing room air [ppm]*

$c_a(t)$ = *carbon dioxide concentration at time t [ppm]*

From this relationship the leakage of carbon dioxide was calculated for different amounts of air recirculation. The amount of carbon dioxide discharged by leakage per hour can be determined analogue to the calculations of leakage air:

$$\Phi_{mL} = ((c_i - c_a) \bullet 10^- 6) \bullet \Phi_{vL} \bullet \rho_{CO_2} i$$

The total amount of carbon dioxide loss by air leakage in a period of t=0 till t=t1 amounts:

$$m_L = {}_0\int^{t} 1\, \Phi_{mL}(t) dt$$

2.4.3 Accumulation of carbon dioxide

The amount of carbon dioxide which can accumulate in air of the growing room and compost was determined from the volume of the air and the compost in the growing room and their carbon dioxide concentrations and densities. The accumulation of carbon dioxide in the air of the growing room and the compost during a period $t=t_n$ till $t= t_n+ \Delta t$ is determined by:

$$accumulation_{t_n} \int^{(t_n+\Delta t)} \bullet \frac{dm_{CO_2}(t)}{dt} = (m_c(t_n) + m_i(tSUBn)) - (m_c(t_n + \Delta t) + m_i(t_n + \Delta_t))$$

The carbon dioxide accumulated in the growing room air is calculated by:

$$m_i(t) = ((c_i(t) - 10^- 6) - V_i - \rho_{CO_{2i}})$$

and the carbon dioxide accumulated in the compost as follows:

$$m_c(t) = ((c_c(t)\_10^- 6)\_V_c\_\rho_{CO_{2c}})$$

$c_c(t)$ = CO_2 *concentration of the compost air [ppm]*

$m_i(t)$ = CO_2 *mass of the growing room air [kg]*

$m_c(t)$ = CO_2 *mass of the compost air [kg]*

V_i = *volume of the growing room air* $[m^3]$

V_c = *volume of the compost air* $[m^3]$

$\rho_{CO_{2i}}$ = *density of* CO_2 *inside the growing room air [kg_m - 3]*

$\rho_{CO_{2c}}$ = *density of* CO_2 *inside compost air [kg_m - 3]*

3. Results

The carbon dioxide production rate was determined for twenty eight vegetative phases and seven first, seven second and seven third flushes and the correlations were determined with the following factors: average compost temperature, average vapour pressure and average carbon dioxide pressure in compost and the differences between compost and growing room air of the temperature, vapour pressure and the carbon dioxide pressure. A distinction was made between the vegetative phases and the flushes because during the flushes the total interchanging area of the growing beds was increased by the number and the size of the mushrooms on the bed.

3.1 Correlations

The correlations of seven cultivations were determined. Those results are shown in Figures 3-8 and Table 3.

Table 3 - Correlations R of temperature, humidity pressure, carbon dioxide pressure in compost and the average differences between compost and growing room air, with the average carbon dioxide production rate per phase. The high correlation-coefficients (> 0.6) are marked in grey.

	average levels in compost per phase			average differences between compost en growing room air per phase		
	temperature	vapour pressure	CO_2 pressure	temperature	vapour pressure	CO_2 pressure
vegetative phases n = 28	0.94	0.94	0.87	0.76	0.86	0.82
first flush n = 7	0.68	0.70	-0,59	-0.09	0.19	-0.63
second flush n = 7	0.72	0.66	-0.18	-0.06	0.64	-0.24
third flush n = 7	0.64	0.63	-0.34	0,24	0.68	-0.40

4. Conclusion and discussion

Heat and carbon dioxide production and the climate conditions in the growing room depend on the physical, biological and chemical compost quality and the environmental conditions in the beds and growing room air. The total of heat and carbon dioxide produced by micro organisms, mycelium and mushrooms can be considered as measurable quantities of activity as the carbon dioxide production rate has shown to be a measure of the biological activity in mushroom compost (Wiegant, 1992) and soils (Anderson & Domisch, 1972).

It appears that, during the vegetative phases, the average compost temperature, carbon dioxide and vapour pressure in compost are strongly positively correlated with the average carbon dioxide production. No strong correlations were found between the average levels per phase of CO_2 pressure in compost and the average carbon dioxide production rates per phase during the flushes.

A possible reason for this influence on the discharge of carbon dioxide might be the increase of the growing bed surface by the quantity and the size of the fruit bodies. The produced heat and carbon dioxide are discharged easier but with varied resistance. This might explain the variation in average carbon dioxide production rate per phase during the flushes caused by almost equal climate circumstances.

It appears that the average temperature difference between compost and growing room air during the vegetative phases do correlate with the average carbon dioxide production while during the flushes no correlation was found. The vapour pressure difference between compost and growing room air do correlate with the average carbon dioxide production during the vegetative phases and the second and third flush but not during the first flush. The carbon dioxide pressure difference per phase between compost and growing room air is positively correlated with the average carbon dioxide production rate during the vegetative phases and negatively correlated during the first flush while during the second and third flush no correlation was found with the carbon dioxide production per phase. During the flushes higher average carbon dioxide productions seems to be occur at lower levels of CO_2 pressure in compost and lower CO_2 pressure differences between compost and growing room air.

The obtained correlations can be used to check whether or not the carbon dioxide production rate of the cultivation bed can be predicted from the existing climate parameters. These relationships might be used for modification of the environmental control strategy and cultural measures.

5. References

Anderson, J.P.E. & K.H. Domisch, 1972. A Physiological method for the quantitative measurement of microbial biomass in soil. Soil Biol. Biochem. 10, 215-221

Loeffen, H., 1993. CO_2-produktiesnelheid als maat voor groei van de champignon *Agaricus bisporus*. IMAG-DLO rapport no. 93-15

Wiegant, W.M., 1992. Growth Characteristics of the Thermophilic Fungus Scytalidium in Relation to Production of Mushroom Compost. Applied and Environmental Microbiology. Vol. 58, 1301-1307

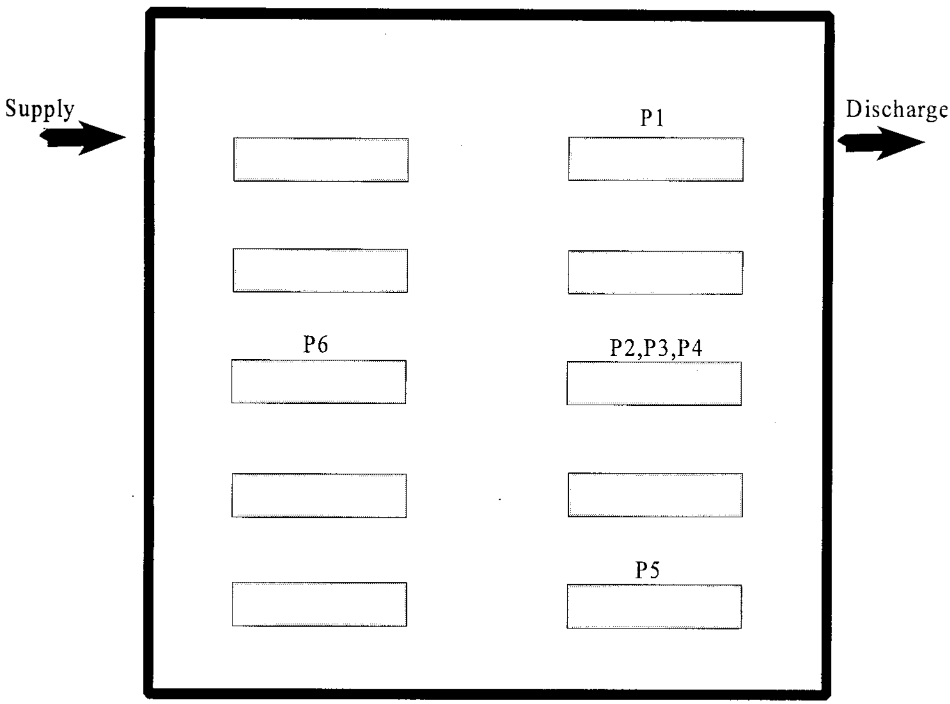

Figure 1 Places of measurements in the mushroom growing room.

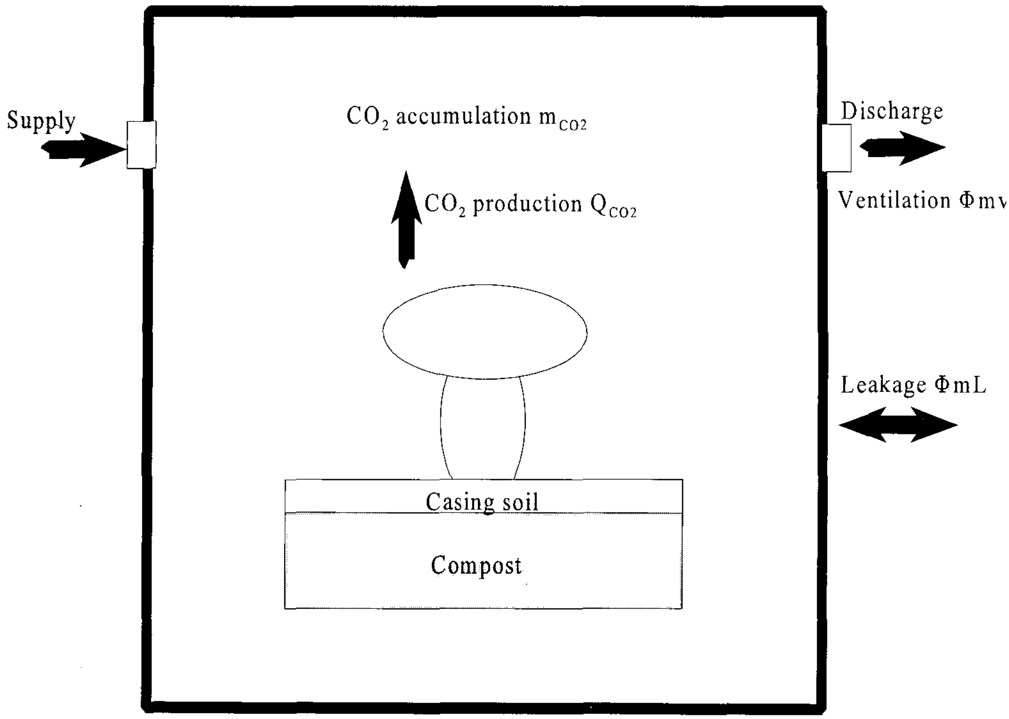

Figure 2 Carbon dioxide balance of the growing room.

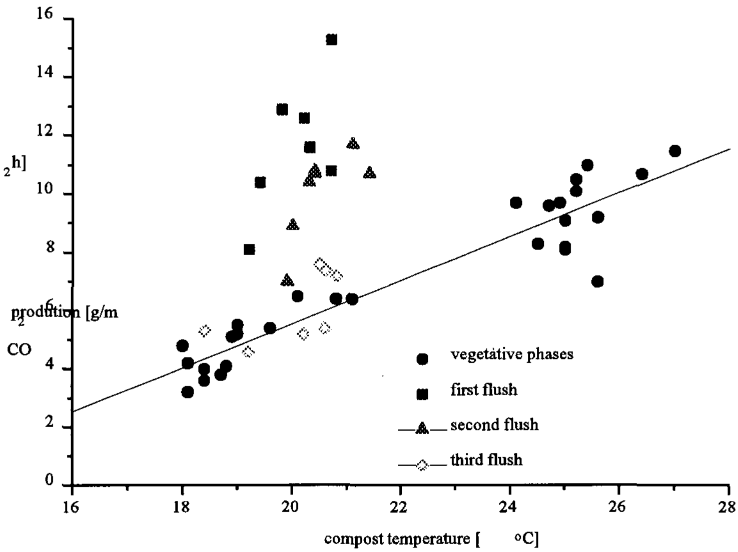

Figure 3: Relation between compost temperature and the CO_2 production per phase

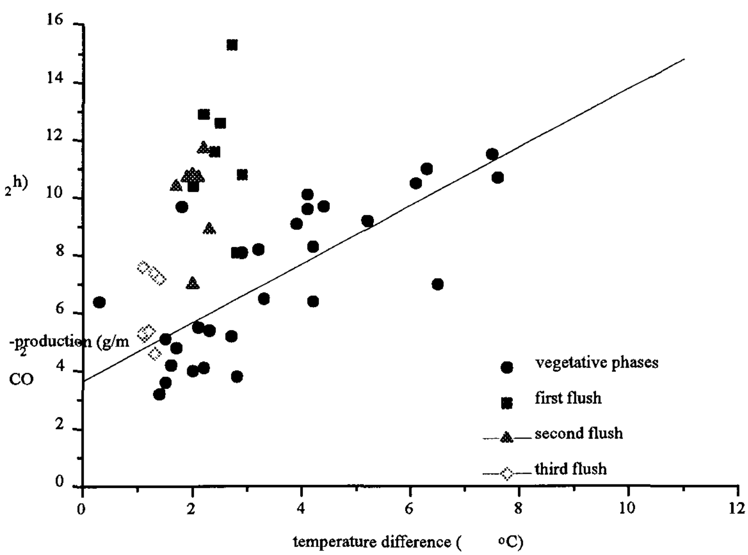

Figure 4: Relation between the temperature difference and the CO_2 production per phase

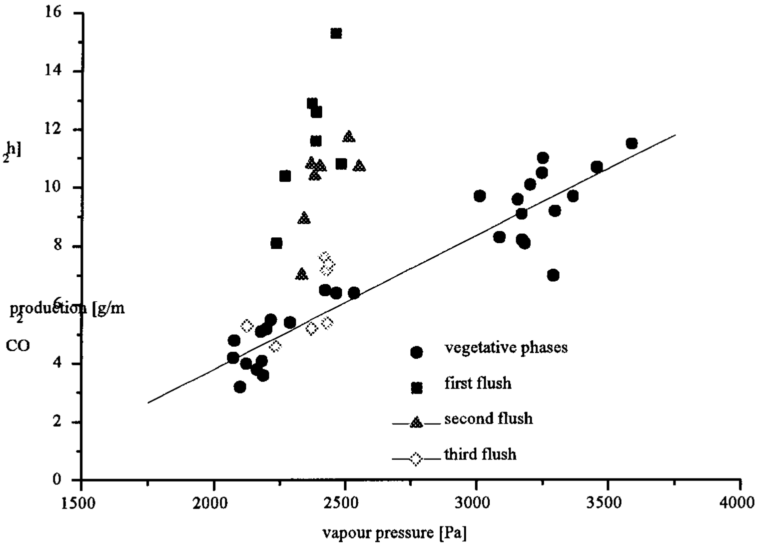

Figure 5: Relation between the vapour pressure in compost and the CO_2 production per phase

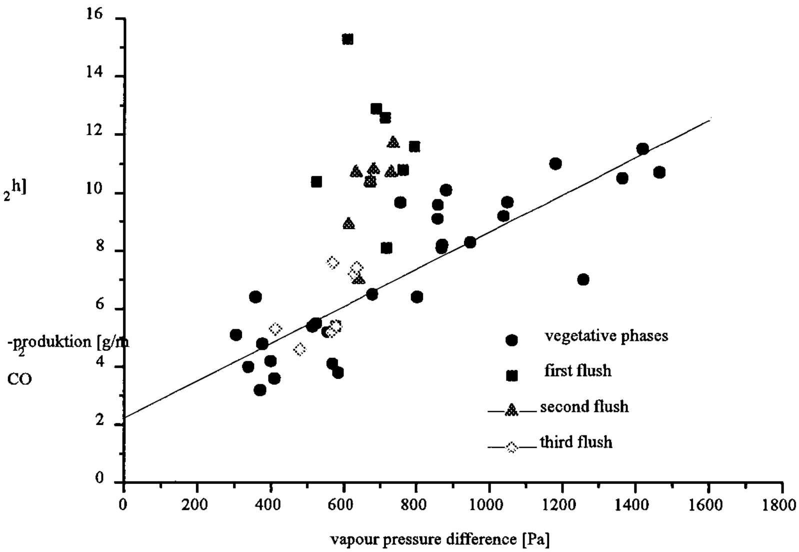

Figure 6: Relation between the vapour pressure difference and the carbon dioxide production per phase

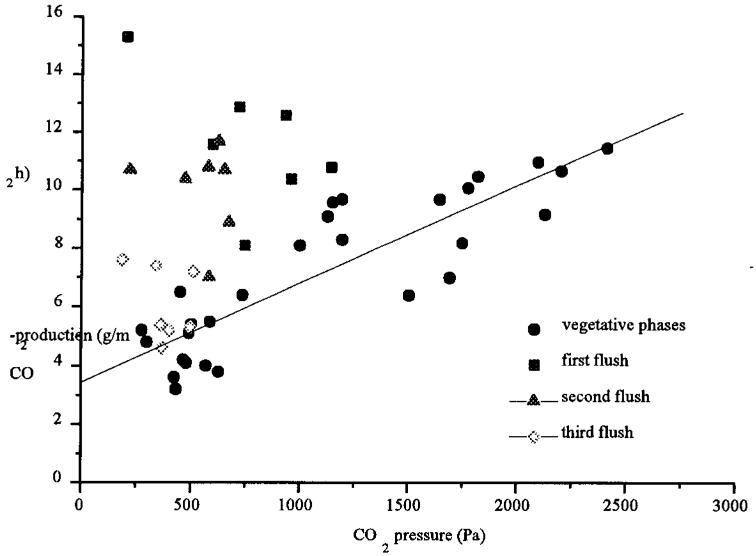

Figure 7: Relation between the CO_2 pressure in compost and the CO_2 production

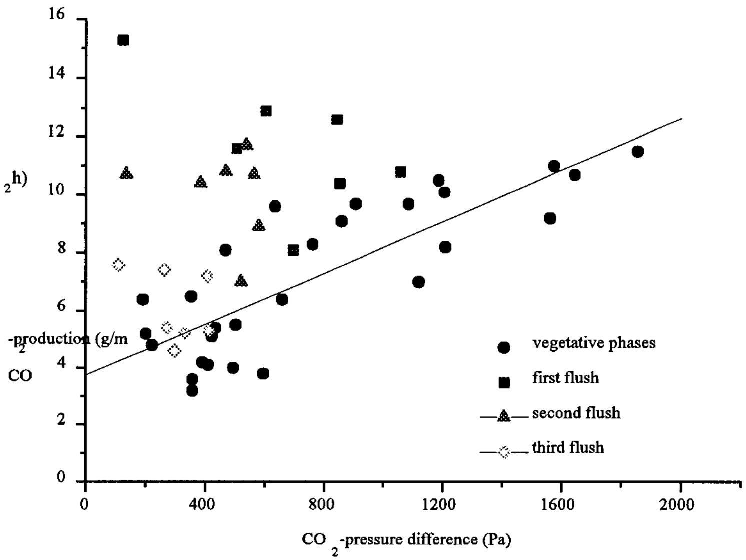

Figure 8: Relation between CO_2 pressure difference and CO_2 production