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EFFECT OF SLUDGE TREATMENT PROCESSES ON *ASCARIS* DESTRUCTION FOR SAFE UTILISATION OF SEWAGE SLUDGE IN EGYPT

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ABSTRACT

Two different types of sludges from two popular sewage treatment systems were used in this study; namely, anaerobic pond sludge from a wastewater stabilisation pond system and filter pressed primary sludge from a primary sewage treatment plant. Under Egyptian conditions, *Ascaris* eggs represent the main health concern for sludge application on land and, accordingly, the effect of sand drying beds and a passive composting system (using agricultural wastes as bulking agents and cement dust as an additive to the sludge) were studied in terms of the inactivation of *Ascaris* eggs.

From the characterisation and assessment of the anaerobic pond sludge from the Mit Mazah wastewater stabilisation pond system, it has been concluded that the sludge was well digested and free of viable *Ascaris* eggs. Consequently, this sludge is considered to be safe for land application, after appropriate dewatering.

For the purposes of the study, anaerobic pond sludge was seeded with *Ascaris vitilorum* eggs (cattle ascarid). Within 30 days of dewatering on sand drying beds during the winter season (October and November), the *Ascaris* eggs were found to be inactivated only in the top layers, where the average solids content was approximately 85%. By the end of the two month drying period, the middle and bottom layers of sludge on the drying beds contained an average solids content of 74% to 77% and 72 to 73%, respectively, yet viable *Ascaris* eggs were still detected. During a second sludge application during the winter season (December and January), unfavourable weather conditions prevailed and, by the end of the 60 days drying period, total solids content averaged 54% in the top layer of sludge. The middle and bottom layers had an average total solids content of 49% and 44%, respectively. Throughout the winter drying period, all samples collected were positive for viable *Ascaris* eggs throughout the full depth of sludge. However, during the summer season, samples collected from the drying beds after 17 days of drying did not contain viable *Ascaris* eggs in the top sludge layers, where the solids content ranged from 74% to 63%. After one month of summer drying, no viable *Ascaris* eggs were detected throughout the entire depth of sludge on the drying beds and the lowest solids content recorded was 80% for the bottom layers.

From this study, it can be concluded that, during the wet season in Egypt, drying beds were not efficient in destroying *Ascaris* eggs throughout the entire sludge depth. During the summer season, *Ascaris* eggs can be inactivated much more rapidly, compared to the winter season. Desiccation does not seem to be the only factor influencing the destruction of *Ascaris* eggs, with sludge temperature, solar radiation intensity and exposure time being possible major factors.

By comparing the composting of filter pressed primary sludge in passive and windrow piles (used as control piles), it has been proved that the passive composting system is much more efficient in maintaining regular high temperatures in the composting mixture for a much longer duration (additional 10 days), due to the favourable aerobic conditions. Moreover, passive composting preserves the nitrogen content through the naturally controlled internal temperature, less need for turning and lower loss of moisture. By the end of the composting process, the total nitrogen content for the passive and windrow piles was a gain of 17.5% and a loss of 0.7%, respectively, while the ammoniacal nitrogen content in the product was 1109 mg/l and 837 m/l, respectively. From the hygienic point of view, passive composting technology proved to be much more effective in inactivating *Ascaris* eggs present in the primary sludge, compared to the windrow pile system. Viable *Ascaris* eggs were not detected after 30 days of composting using the passive system, compared with 60 days of composting for the windrow pile.

Industrial cement dust as an additive and agricultural wastes (from fennel and basil production) were incorporated with sludge to form a range of composing mixtures. From the sludge/cement dust composting piles with agricultural wastes as bulking agent, it can be concluded that more than 35% concentration of cement dust was unfavourable for the decomposition process, due to the high pH and high temperature levels attained as a result of the effect of cement dust and dehydration of the organic matter. Moreover, loss of nitrogen was very high, due to the release of ammonia, encouraged by the high pH and high temperature in the composting mixture. The passive composting system was very efficient in naturally controlling the internal temperature in all the sludge/cement dust piles with bulking agent. Excessive heat was released to the atmosphere through the chimney effect created by the circulation of air through the perforated pipes and upwards into the pile. Internal temperatures for even the piles with the highest proportion of cement dust did not exceed 73°C. Inactivation of *Ascaris* eggs was achieved after only 15 days of composting for all the different cement dust concentrations, mainly due to the influence of high pH and high temperature levels for long periods but may also be due to the high release of ammonia gas.

The passive composting of sludge amended with 30% cement dust without bulking agent was inefficient for both the decomposition process and inactivation of *Ascaris* eggs. No biological activity was taking place during the two months fermentation stage, due to the prevailing anaerobic conditions (lack of air voids and high moisture content)

By considering all the different parameters for evaluating a treated compost, including the stability, maturity, nutrient content, heavy metals content and viable *Ascaris* eggs content for the sludge/cement dust piles with bulking agent, it can be concluded that more than 30% cement dust concentration would be unfavourable, according to the relatively high loss of nitrogen. More than 35% cement dust concentration is certainly unfavourable, mainly as a result of the delay of the decomposition process, the elongation of the composting period and the high loss of nitrogen content. There is no need to separate out the agricultural waste bulking materials after composting because they are organic in nature. Likewise, there is no need to consider separating out the cement dust, as the physicochemical analysis of the final sludge/cement compost with bulking materials showed its suitability for adding to agricultural land as an amendment.

In conclusion, sand bed drying is considered to be a suitable process for dewatering of anaerobic stabilisation pond sludge in Egypt and, for extended periods between pond desludging of the order of 6 years, the dewatered sludge will be suitable for direct application to agricultural land. Passive composting is an appropriate technique for preparation of Egyptian filter pressed primary sludge for safe application to agricultural land. Cement dust additions of less than 30% concentration, to the composting mixture in a passive composting system produces sanitised and mature compost. The potential for co-disposal of agricultural wastes and cement kiln dust as bulking agents and additive, respectively, with sewage sludge in the production of compost, is very promising to produce a safe and beneficial outcome to the community.

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LIST OF ABBREVIATIONS

BOD_5	Biological oxygen demand
COD	Chemical oxygen demand
CWO	Cairo Wastewater Organisation
DS	Dry solids
EC	European Community
EEAA	Egyptian Environmental Affairs Agency
HRT	Hydraulic retention time
kg	kilogram
l	litre
m	meter
max.	maximum
mg	milligram
min.	minimum
mm	millimetre
MRT	Mean residence time
NOPWASD	National Organisation for Potable Water & Sanitary Drainage
°C	degree Celsius
PFRP	Processes to further reduce pathogens
PSRP	Processes to significantly reduce Pathogens
PTEs	Potentially toxic elements
s	second(s)
STP	Sewage treatment plant
t	time
TS	Total solids
TSS	Total suspended solids
TVS	Total volatile solids
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
WSP	Waste stabilisation pond(s)
WWTP	Wastewater treatment plant
y	year

CHAPTER ONE: INTRODUCTION

1.1. Introduction

One of the most urgent problems confronting many countries is the disposal of their sewage sludges in a manner that is environmentally acceptable, economically feasible, and, above all, is not hazardous to human health. This problem emerged due to the fact that sludge quantities generated are steadily increasing, while the restrictions on disposal are steadily becoming tighter. The costs of the present methods of sludge disposal (e.g. incineration, landfilling, trenching, lagooning, etc.) are increasing rapidly and without beneficial return. Moreover the development and implementation of wastewater collection and treatment schemes to serve the majority of urban populations are receiving increasing priority in most countries, even in developing countries.

Consequently, many municipalities are now considering land application methods for the utilisation of their sewage sludges. This procedure has been shown to be beneficial to crop growth because of the essential plant nutrients contained in sludges, as well as being a good method of ultimate disposal. However, this outlet imposes a high level of sanitisation and stabilisation of sewage sludge in order to maintain soil, water and air qualities. Because of the microbial pathogens present in sewage sludge, there is considerable concern over the possibility of disease transmission through the food chain as a result of the spreading of untreated sewage sludges onto land. Accordingly, it is essential that pathogens be inactivated to as large an extent as possible before land disposal of wastewater and sludges.

The potential transfer of pathogens from sludge to humans under Egyptian conditions is of real concern, mainly due to the following:

- prevalence of a wide range of pathogens in sewage,
- limited facilities, restricted to urban areas, for treating sewage sludges (generally sophisticated expensive methods are used, which are not affordable for rural areas), and

- the widespread use of manual labour on land, having close contact with sludge.

It is clear that rural areas are frequently overlooked by governments, especially in developing country like Egypt, although the main health hazard arises in such areas. According to very recent research work carried out on Egyptian sewage sludge, pathogens, and especially *Ascaris* ova, represent the main health hazard in land application of sewage sludges. Accordingly, the Egyptian Government has planned that by the year 2010, most rural areas and villages will be connected to sewer networks and treatment plants. It is estimated that, by the year 2020, sewage sludge production will have doubled, reaching nearly half a million tonnes of dry solids for disposal every year. Such a huge quantity, if treated in a cheap and efficient process for the destruction of parasites, would highly benefit Egypt allowing land application for the reclamation of the 95% desert land areas.

Any beneficial meteorological and socio-economic conditions should also be taken into consideration in planning systems for sewage sludge collection, treatment and disposal. Accordingly, the tropical climate of Egypt is a great advantage in making several cost effective sludge treatment processes more efficient than they would be in temperate or cold climates. The low cost and high availability of manual labour also provide advantageous conditions for simple systems minimising the need for equipment and complex operations.

With the infrequent desludging associated with waste stabilisation ponds treatment, drying beds are likely to be an appropriate treatment approach. However, for the more regular production of sludge from conventional sewage treatment plants (primary, secondary or activated sludge treatment plants), composting is likely to be a viable process to prepare safe sludges to be used for land application. The current study was organised to assess the two techniques for the two types of sludges indicated.

1.2. Aims of the Study

This study particularly focused on the effects of sand drying beds and composting on the inactivation of *Ascaris* ova found in sewage sludges which, under Egyptian conditions, represent the main health hazard associated with land application of sewage sludge. The types of sludge investigated were anaerobic pond sludge from a waste stabilisation pond system in Daqahlia Governorate, due to the expected widespread use of pond systems in the future in rural Egypt, and primary sludge from a primary sewage treatment Plant in Alexandria.

According to the literature surveyed and data gathered (presented in Chapter 2), several important issues had not previously been sufficiently studied and this research was designed to address these issues. According to several researchers (Mara and Pearson, 1987; Feachem et al., 1983, etc.) it is generally believed that the physicochemical and microbiological quality of wastewater stabilisation pond sludges is better than those of sludges from conventional sewage treatment plants. However, few published data indicate the safe application of any sewage sludge onto agricultural land without the necessity for further treatment. Moreover, little is known about the viability of *Ascaris* ova after prolonged storage periods in anaerobic ponds. The effects of the sand drying bed process on the dewaterability of anaerobic pond sludge and on the inactivation of *Ascaris* ova have been studied by a few researchers, but, under Egyptian conditions, have not been studied. According to extensive research work on composting systems, by many researchers, the aerated static pile system is the most efficient for producing a safe, sanitised and well digested compost. However, passive composting, which is the simple and cheap alternative to the static aerated pile system, has not been studied in terms of its effect on the digestion process and on the survival of *Ascaris* ova. Little research has recently been undertaken on the addition of alkaline amendments to the compost mixture, for studying their effect on the final product. However, cement kiln dust, which is a hazardous waste produced by the cement industry in Egypt, has not been studied for its effect on the digestion process and on the inactivation of *Ascaris* ova.

Based on the gaps in knowledge identified by the literature review, the aims of this study were defined as:

- Characterisation and assessment of the accumulation pattern and quantity of anaerobic pond sludge.
- Effect of sand drying bed dewatering on the inactivation of *Ascaris* ova in anaerobic pond sludge.
- Effect of passive composting on the digestion of primary sewage sludge and inactivation of *Ascaris* ova.
- Effect of cement kiln dust and other waste amendments on the digestion of sewage sludge and inactivation of *Ascaris* ova in the passive composting process.

These aims were expected to result in the identification of new and promising alternatives for establishing and eventually, encouraging the spread of such cost effective, easy to operate and highly efficient techniques for sewage sludge processing. This would produce a beneficial outcome to the community for the disposal of residual wastes (sewage sludge, agricultural wastes and cement kiln dust), a solution which would be environmentally acceptable rather than a health hazard and accumulating burden on local and central government, private and public sectors.

CHAPTER TWO: LITERATURE REVIEW

2.1. Waste Stabilisation Ponds

Waste stabilisation ponds (WSPs) are large, shallow man-made ponds covering large areas and are the simplest and most economical process of sewage treatment wherever land is available at relatively low cost. Their principal advantage in warm climates is that they achieve low survival rates of excreted pathogens at a much lower cost than any other form of treatment, with maintenance requirements simpler by several orders of magnitude. In fact, a pond system can be designed to ensure, with a high degree of confidence, the total elimination of all excreted pathogens. This is not usually achieved because the incremental benefits resulting from achieving zero survival, rather than low survival, are less than the associated incremental costs. Yet waste stabilisation ponds are the best form of treatment in tropical, developing countries because they can achieve any desired level of pathogen removal. From a strictly health viewpoint, the fact that ponds can do this at lowest comparable cost is an additional advantage.

The degree of treatment achieved is a function of the number of ponds in the series, and the retention time of the wastewater in each pond. Generally, various pond combinations could be used to develop a successful treatment train. However, the choice and configuration of ponds in a treatment plant depends on several factors, most important of all are the following:

a. Strength of influent waste.
b. Effluent quality objective (for restricted/unrestricted irrigation, or discharged into canals and drains).
c. Land availability.

2.1.1. Treatment Mechanisms

The driving force in a waste stabilisation pond is the solar energy utilised in photosynthesis. The action of sunlight on algae in the pond enables them to grow and consume the nutrients contained in the sewage. Also essential to the process are the large numbers of aerobic bacteria in the pond, which break down organic solids in the sewage, making their nutrient content available to the algae. The carbon dioxide released as the bacteria work on the organic solids is also utilised by the algae in their growth through photosynthesis.

The algae and bacteria are inter-dependent (symbiotic or commensal). While the algae use the nutrients and carbon dioxide released by bacterial decomposition, the aerobic bacteria make use of and need the oxygen liberated by the algae during photosynthesis. The nutrients contained in sewage include nitrogenous compounds, phosphates and potassium. In stabilisation ponds, through the activities of algae, these nutrients are removed from solution and concentrated in the algal cells.

There are four major types of ponds in common use, each having a unique treatment mechanism:

i. Treatment in anaerobic ponds:

Anaerobic ponds are deep ponds receiving a high organic loading such that anaerobic conditions prevail throughout the entire pond depth. The successful operation of an anaerobic pond depends on the delicate balance between the acid-forming bacteria and the methanogenic bacteria; thus a temperature >15°C and pH >6 is necessary. Under these circumstances sludge accumulation is minimal. Anaerobic ponds have retention times of 1-5 days and depths of 2.5-5.0 m.

During the slow passage of wastewater through an anaerobic pond, and after some time has elapsed, the following changes will have taken place:

a. Most of the suspended solids will have settled to the bottom of the pond. Some removal of pathogenic organisms will have been achieved.

b. Floating material, including oil, grease, plastics, etc., will have been carried to the surface, where they will build up in a scum layer. Scum baffles or similar devices will subsequently prevent scum from leaving the pond with the effluent.

c. Part of the suspended solids, including worm eggs, parasites and bacteria, settle to the bottom of the pond. Here they undergo anaerobic decomposition, concentration and part mineralization.

d. The organic material is broken down by anaerobic bacteria. Through the metabolism of these bacteria, part of the organic matter is converted into mineral matter. During this phase, gases are generated, primarily CO_2, CH_4 and H_2S, which are dispersed into the atmosphere through the liquid surface. A portion of the sludge resulting from the settling of solids will be transformed into gas. The reaction, together with sludge thickening, accounts for the very slow build-up of solids in an anaerobic pond.

The liquid effluent from the anaerobic pond will have low levels of suspended and settleable solids and worm eggs. In terms of BOD_5, the effluent will often have a 40-60% reduction in concentration from that in the raw influent.

ii. Treatment in facultative ponds:

The term facultative refers to a mixture of aerobic and anaerobic conditions and in a facultative pond aerobic conditions are maintained in the upper layer "floating" upon an anaerobic lower one. The aerobic conditions in the upper layer is due to the presence of dissolved oxygen; this is primarily generated as a result of photosynthesis caused by the incidence of solar radiation upon the algal population of the pond, as well as mixing through the liquid surface interface by wind.

Aerobic and facultative bacteria in the upper and middle layers metabolise the dissolved, colloidal and suspended organic matter, consuming dissolved oxygen and producing CO_2. Facultative bacteria also consume combined oxygen from nitrates and sulphates when free oxygen is exhausted.

During the passage of wastewater through a facultative pond, the following changes may be observed:

a. Most of the remaining suspended solids settle to the bottom of the pond, where they develop a layer that works like an anaerobic pond or sludge digester. This is the anaerobic zone of a facultative pond.

b. Above the anaerobic sludge layer, an intermediate zone exists in which dissolved oxygen is present some of the time, fed from the upper layer. The intermediate zone is greenish in colour due to the presence of algae.

c. The upper layer is a natural culture medium for algae and operates as an aeration system, producing oxygen for the aerobic and intermediate zones. The oxygen concentration varies with depth and with the time of day. At night, there is no oxygen production, but some surface diffusion of atmospheric oxygen occurs.

d. The algae in the upper layer coexist with bacteria in a synergistic relationship. Bacteria consume oxygen in respiration and multiplication and, at the same time, they break down organic matter present in the wastewater. As a by-product of their metabolism, they release CO_2 into the liquid, as well as nitrates, sulphates, phosphates and other mineral salts. Algae, in turn, use these by-products when they absorb light to synthesise their own cellular material, releasing oxygen. Some of this oxygen is then consumed by the aerobic bacteria, continuing the cycle.

e. The effluent taken from the surface layer of a facultative pond is usually strongly green-coloured because of the presence of algae. It also contains other living organisms, such as bacteria and rotifers, and can have a high concentration of dissolved oxygen.

iii. Treatment in aerated ponds:

Aerated ponds are activated sludge units operated without sludge return. They are now usually designed as completely mixed non-return activated sludge units. Floating aerators are most commonly used to supply the necessary oxygen and mixing power. Surface aerators may be fixed in one position or used as floating units. Generally, 10 to 20% of the total oxygen required results from oxygen transfer across the surface interface, and the rest is provided through mixing and entrapment of air. Aerated ponds achieve BOD_5 removal > 80% at comparatively long detention times (2-6 days), whereas detention times less than 2 days are not recommended as they are too short to permit the development of a healthy flocculant sludge.

Aerated ponds operate at approximately one-tenth of the mixed liquor suspended solids (MLSS) concentration of a regular activated sludge system. The lower MLSS requires only a fraction of the aeration capacity of a conventional or extended aeration activated sludge system and will consume less than one-tenth of the power. Moreover, these ponds are particularly applicable when the availability of land is limited. Accordingly, it is the simplest and often the best alternative to replace the facultative pond. However, aerated ponds are not particularly effective in removing faecal bacteria; FC reductions are only 90-95% and further treatment is therefore necessary.

iv. Treatment in maturation ponds:

Maturation ponds are used mainly for reduction of pathogenic organisms. Besides removing a very high percentage of faecal bacteria, viruses, protozoa and other pathogens, maturation ponds may also remove some algae and some nutrients. The bactericidal effect of maturation ponds is due to several natural factors, including sedimentation, lack of food and nutrients, solar ultra-violet radiation, high temperature, high pH value, the toxins and antibiotics exerted by some organisms, as well as natural die-off. These ponds should only be used to upgrade the effluent from a facultative or aerated pond. They should not receive raw wastewater nor anaerobic pond effluents.

Maturation ponds are normally designed for a retention time from 3 to 10 days per pond when two or more are in series (a minimum of 5 days when only one is used), while typical depths range between 1.0-2.0m. According to Horan (1990), this depth is advisable since the destruction of viruses is better in shallow ponds than in deep ones. The effectiveness of maturation ponds in removing pathogens is conveniently assessed by the removal of faecal coliforms. With proper design, faecal coliform removals > 99.99% can be achieved.

The major function of each type of pond is summarised in **Table 2.1.**

Table 2.1. Principal Functions of Pond Types & Typical Performance Data

Pond	Depth (m)	Detention time (d)	Major role	Typical removal efficiencies
Anaerobic	2-5	3-5	• sedimentation of solids, • BOD removal, • stabilisation of influent • removal of helminths	BOD: 40-60%, SS: 50-70%, Faecal coliforms: 1 log, helminths: 70%
Facultative	1-2	4-6	• BOD removal	BOD: 50-70%, SS: increases due to algae, faecal coliforms: 1 log
Aerated	2-4	2-6	• BOD removal	BOD: 80% Faecal coliforms: 90-95%
Maturation	1-2	12-18	• pathogen removal. • nutrient removal.	BOD: 30-60%, SS: 20-40%, faecal coliforms: 4 log, nitrogen: 40-60%, helminths: 100%.

Source: Horan (1990).

2.1.2. Effects and Benefits of Ponds

Stabilisation ponds have a significant effect on both effluent and sludge quality. Most authors who worked on stabilisation ponds refer to the system as "the cheapest method of sewage treatment in hot climates and potentially the most powerful in removal of pathogens from effluent" (Mara, 1976; Feachem et al., 1983; Horan, 1990; etc.). Ponds have a great reputation for high removal of helminth ova from the wastewater, and **Table 2.2** summarises the published information from selected sites.

The sludge accumulated in wastewater stabilisation ponds is involved in the overall treatment process, due to the anaerobic digestion of sedimented organic matter and to the trapping of undegradable solids. The digestion of organic matter takes place rapidly as far as the easily hydrolysable fraction is concerned. The digestion of the slowly hydrolysable solids, however, still goes on in the deeper layers until the sludge is removed by desludging.

Little information is available about the effect of WSP, or more precisely of anaerobic ponds on the inactivation of helminth eggs. The adequate period of time required for desludging anaerobic ponds, after ensuring the inactivation of helminth eggs is not clear in the literature. According to Feachem et al. (1983), the eggs of parasites settling in the sludge layer will die after a few months. Other authors stress the fact that parasite eggs, and especially *Ascaris* ova, tend to survive under anaerobic conditions in the sludge layer for long periods, and according to Strauss (1985) more than 12 months.

Accordingly, knowledge of the phenomena which will affect the final characteristics of the sludge is limited and worthy of research. The literature available on sludge accumulation and characterisation in anaerobic ponds is reviewed in Section 2.2.2.

Provided sufficient land is available at reasonable cost and proximity to the sources of wastewater, the case for choosing stabilisation ponds for sewage treatment in developing countries is overwhelming. BOD and pathogens can be removed from sewage at less capital and operating cost than in conventional plants, and ponds are particularly effective where maintenance skills are limited, since maintenance can be carried out by unskilled labour under minimal supervision. Moreover, conventional sewage treatment plants require regular sludge removal, resulting in a demand for large areas of drying beds or sophisticated and expensive sludge disposal facilities. On the other hand, anaerobic ponds will only require desludging every two or three years, and facultative and maturation ponds are generally capable of functioning satisfactorily for over 20 years before sludge build-up reaches a level that necessitates its removal.

Table 2.2. Literature Survey on the Removal of Helminth Eggs from Different Types of Waste Stabilisation Ponds

Type of Pond	Initial concentration of eggs in raw wastewater (eggs/l)	Depth (m)	Mean hydraulic detention time (days)	Removal of helminth eggs (%)	Country	Reference
1F+3M	-	1.75, 1.2 each	37, 5	100	Kenya	Pearson et al. (1996)
2A+3F+3M	158	4, 1.2 each, 1.2 each	1.2, 11, (11, 12.6, 4)	100	Kenya	Ayres et al. (1993)
Three pond system	-	-	6	100	India	Lakshminarayana et al. (1969)[a, b]
A+3M	23	1.5, 0.6 each	33 hrs. total	100	USSR	Koltypin (1969)[b]
1A+1F+3M	376	1.25, 1, 1 each	4, 32, 3.2 each	100	Brazil	Ayres et al. (1993)
2A+4F+4M	307	5, 2, 1.25	32-48	100	Jordan	Saqqar & Pescod (1992)
Microphytic	11.7	1.6	50	100	Marrakech	Ouazzani et al. (1993)[c]

[a, b] Cited by Feachem et al. (1983).

According to author, most eggs were removed in first anaerobic pond.

[c] Cited by Hindiyeh (1995).

A: Anaerobic pond.

F: Facultative pond.

M: Maturation pond.

The effluent from waste stabilisation ponds is rich in nutrients through its algal content, which can be a good source of food for edible varieties of fish, or for irrigation purposes. Alternatively, with careful design and good monitoring, tertiary and subsequent ponds can be used for aquaculture. On the other hand, effluent from conventional plants is seldom suitable for agricultural reuse due to its high pathogen content, unless costly tertiary treatment processes are incorporated.

2.2. Anaerobic Pond Sludge

The presence of pathogenic organisms is regarded as a serious drawback to sludge disposal on land. In addition, at localities where industrial wastes are not well monitored, heavy metals and other compounds at toxic concentrations present a major health hazard to people and animals. Dealing with pathogens and heavy metals in sludges generated from conventional treatment plants has always been a problem and requires high investment costs (equipment, chemicals and qualified technicians). On the contrary, a significant advantage for waste stabilisation pond systems is the quality of the accumulated sludge. Due to the operational mechanisms, anaerobic ponds efficiently stabilise and digest the sludge to a great extent, even under overloading conditions in respect of wastewater flow (WHO, 1992). Most important of all, helminth eggs are inactivated, thus producing a safe, sanitised and beneficial sludge that requires only dewatering before final disposal onto land. Anaerobic ponds also efficiently pretreat industrial wastewater; for example according to Pearson et al. (1996), heavy metals are removed by the formation of insoluble sulphides which precipitate into the bottom sludge layers, as well as by the degradation of phenol-based hydrocarbons which would otherwise inhibit algal photosynthesis, and thus oxygenation in the facultative and maturation ponds.

The value of anaerobic ponds to reduce land area requirements, particularly for large pond systems, has always been recognised (Mara and Pearson, 1986; Mara et al., 1992; Saqqar and Pescod, 1995) and, according to the study of Pearson et al. (1996) at Dandora WSP in Kenya, including an anaerobic pond could make a land saving of up to 75% on that required for facultative ponds only.

Depending on the desludging period (2 to 3 years), the accumulated sludge is anaerobically digested to varying extents, with great improvement in physical and chemical quality compared with raw sludge from conventional and non-conventional wastewater treatment systems. In addition, the microbiological quality of sludge is greatly improved, with nearly complete inactivation of helminth eggs, and thus the benefit of safe usage of anaerobic pond sludge without further treatment for agricultural purposes is achieved.

According to Outwater (1994), the ultimate disposal of sludge should fulfil four requirements:

i. It should not pollute air or water.
ii. It should be economical.
iii. It should conserve organic matter for beneficial purposes.
iv. It should provide a permanent solution to the disposal problems of treatment plants.

2.2.1. Indicators of Stability

Sewage sludges can be applied to land as liquids (2 to 10% solids), as partially dewatered materials (18 to 25% solids), or as heat dried and air dried products (90 to 99% solids). There are, however, a number of problems that must be considered when these materials are applied to land. Thus, it is of great importance to measure sludge stability and identify the characteristics of interest, depending on the location and method for final disposal of sludge.

According to Day et al. (1998), WPCF (1985) and Vesilind (1975), the criteria that have been used to measure the stability of sludge are volatile solids content, specific oxygen uptake rate, BOD and COD of the liquor, and pathogen indicator organism reductions.

i. **Volatile solids content:** Volatile solids content (VS) has long been used as a measure of the amount of organic matter in sludge. The degree of VS destruction in sludge by a sludge treatment process measures its effectiveness in stabilising its organic content. It has been suggested by WPCF (1985) that only 50 to 75% of the VS in municipal wastewater sludge are readily biodegradable. The remaining organic components in raw sludge consist of relatively stable carbohydrates, and humus-type materials. In aerobic and anaerobic digestion, as might be expected; a strong correlation exists between the reduction in VS percent and aeration or retention time (**Table 2.3**). After some time, the VS level often reaches a constant value, and many investigators have suggested that a steady VS concentration indicates that the sludge has been stabilised.

Table 2.3. Reduction of Volatile Suspended Solids during Aerobic & Anaerobic Stabilisation

Detention time (days)	Sludge *	Reduction VSS (%)
Aerobic		
4	Raw primary	8
8	"	13
16	"	13
32	"	13
5	Raw primary	12
10	"	22
15	"	44
25	"	52
35	"	56
Anaerobic		
5	Mixed	40
10	"	50
15	"	56
20	"	58
25	"	58

Source: Vesilind (1975).
* From pilot plant.

ii. **Specific oxygen uptake:** Specific oxygen uptake rate (SOUR) measures the aerobic metabolic activity rate per unit mass of the sludge. The more readily-degradable organic matter present in the sludge mixed liquor, the higher the SOUR value. Accordingly, many investigators use SOUR to determine the stability of aerobically digested sludge. The oxygen uptake rate of aerobically digested sludge depends on the type of sludge fed to the reactor and the temperature.

iii. **BOD_5 & COD of the liquor:** According to WPCF (1985), The filtrate from raw primary sludge has a BOD_5 of approximately 1000 mg/l. On the otherhand, digested sludge filtrate has a BOD_5 of around 100 mg/l. It might be possible, therefore, to estimate the stability of a sludge by measuring the BOD_5 or COD of the sludge liquor.

iv. **Pathogen indicator organism reduction:** The stability of the sludge from the pathogen indicator organism point of view is important to minimise public health concerns. This parameter is especially important when sludge is applied to land, where the potential for human exposure is greater than for other final sludge disposal methods.

Although there can be many definitions for stabilisation, it is not unreasonable to suggest that a stable sludge is one that can be disposed of without damage to the environment and without creating nuisance conditions.

2.2.2. Characterisation and Analysis

Unfortunately, very little information is available in the literature on the effect of the anaerobic pond stabilisation process on the viability of helminth eggs in pond sludges, or on the potential helminthological health risk from using anaerobic pond sludge for agricultural purposes without further treatment. Moreover, information available on the characterisation of sludge and the pattern of sludge accumulation in ponds is also limited. Little research has been carried out on these topics, and **Table 2.4** summarises the published information on the removal of helminth eggs from anaerobic ponds.

Hindiyeh (1995) studied the physicochemical characteristics of anaerobic pond sludge and found that deep sludge deposits were mostly in the alkaline range (7.0-8.4), and low total volatile solids (percent of total solids), averaging 55%. Results indicated that deep sludge deposits are at an advanced stage of stabilisation, while top sludge layers had higher total volatile solids, reaching 73%, and low pH (6.0), indicating that sludge is in an undigested stage.

Table 2.4. Literature Survey on the Removal of Helminth Eggs from Anaerobic Ponds

Initial concentration of eggs (eggs/l)	Depth (m)	Mean hydraulic retention time (days)	Removal of eggs (%)	Country	Reference
303	5	4.2	84	Jordan	Hindiyeh (1995)
4	3	0.4	100% summer, 79% winter	Marrakesh	Ouazzani et al. (1993)*
307	5	4.0-6.5	87	Jordan	Saqqar & Pescod (1992)

*Cited by Hindiyeh (1995).

Sarkar (1972) worked on two anaerobic ponds located at Nagpur in India that had been operating for five years, in order to determine the quality and pattern of sludge accumulation and stabilisation of the deposits. A summary of the physicochemical analyses reported by him is presented in **Table 2.5.**

Table 2.5. Physicochemical Characteristics of Sludge in Stabilisation Ponds[a]

Parameter	Site I *		Site II *
Location of sampling station	Near sewage inlet	Near centre bund	From wooden platform extending to centre of pond
Colour	Black	Black	Black
Odour	Slightly objectionable	Nil	Slightly objectionable
Texture	Granular with colloidal material	Compact	Granular with colloidal material
pH	6.6	7.2	-
Moisture content (%)	80.0	78.8	81.5
Volatile matter (%)	41.6	26.3	24.1
Total nitrogen (% dry wt.)	2.78	1.3	1.01
Phosphates (% dry wt.)	1.8	1.4	1.5
Potassium (% dry wt.)	0.58	0.5	0.31

Source: Sarkar (1972).

[a]: yearly average values are tabulated.

*: Primary anaerobic ponds.

In general, it was observed that sludge samples from stations located near the banks always had lower water and volatile matter content. Analysis of the sludge deposits, with neutral or alkaline pH and low organic and moisture content, show that the sediment was at an advanced stage of stabilisation. The percent volatile matter was found to decrease as the sampling point moved away from the inlet, indicating that much of the suspended load in the influent is initially deposited mostly around the inlet.

Total nitrogen, phosphate and potassium were estimated by Sarkar (1972) to ascertain the fertiliser value of the sludge. The organic and ammonia nitrogen content which to a great extent represents the organic material in general, were higher in the primary ponds, and became less in the following ponds. The highest values of total nitrogen recorded were 2.78% in site I and 1.01% in site II. Similarly, the phosphate level in the sludge was higher in the first pond, 1.8 to 1.5%, and progressively decreased in the following ponds. Potassium values did not vary significantly and ranged between 0.58 and 0.31%.

Ghosh et al. (1982) also worked on two anaerobic ponds located in Nagpur, India, that were under operation for six years and analysed the deposited sludge from the surface layer to bottom (collecting six different layers vertically) for physicochemical parameters. Their results are summarised in **Table 2.6.**

The lower values of volatile solids, nitrogen, phosphate and potassium in the deeper layers indicate various degrees of sludge stabilisation. It was further observed that the sludge filterability rate was low in the upper four layers of both the ponds compared with that in the bottom two layers. This supports the explanation of some researchers that particles covered with a layer of protein have a high specific resistance, and the filterability of the sludge is reduced with the increase of specific resistance in the upper layers. The BOD_5 of the deposited solids depends largely upon the characteristics of the organic matter and the age of the sediment. It is reported that BOD_5 reduction increases as the sludge depth and age increase.

The conclusions reached by Ghosh et al. (1982) are very similar to other researchers except for the fertiliser value of sludge in relation to the mentioned classification of the sludge layer. Their findings can be summarised as follows:

i. The moisture and total solids contents of all the layers were similar. An increasing trend of ammonia and decreasing trend of nitrate quantity were observed in the lower layers.

ii. Significant decreases of volatile solids, nitrogen, phosphorus and potassium were recorded for the deeper layers.

iii. The reduction of nutrients in the lower layers of the sludge deposits was attributed to the following factors:

    a. Denitrification of nitrogenous compounds in the lower layers led to an increase of ammonia, decrease of nitrates and escape of elemental nitrogen into the water above the sludge layer.

    b. Diffusion of oxidizable compounds in the deeper layers towards the upper zone due to changes in viscosity and temperature.

iv. The NPK values of the composite samples of the first two layers of the sludge, i.e. the solids deposited over the last two years of operation of the sewage stabilisation ponds, were compared with those of all the six layers combined. The former showed an increase of 27, 32 and 25% in the values of N, P and K, respectively, from that of the latter.

v. The first two layers of the sludge bed were recommended to be used as fertiliser for croplands after proper disinfection through refuse/sludge composting or sun drying. The deposits from the lower layers are useful for conditioning sandy as well as lower grade soils.

The same pattern of vertical profile analysis as conducted by Ghosh et al. (1982), was studied by Carre et al. (1987) on the first of a series of waste stabilisation ponds of La Chapelle Thouarult in France, in order to characterise the effects of the maturation of the sludges. The samples were taken in the summer, near the inlet and near the outlet of the anaerobic ponds. Considering the respective positions of these points, the difference between the sludges would be maximal.

Table 2.6. Various Parameters of Different Layers of Ponds 1 & 2

Parameter	Pond	Mean values in layers					
		1 (top)	2	3	4	5	6 (bottom)
Moisture (%)	1	8.25	9.03	7.06	7.32	7.02	7.13
	2	6.87	6.81	6.29	6.76	6.95	6.80
Total solids (%)	1	91.75	90.97	92.94	92.67	92.98	92.87
	2	93.13	93.19	93.71	93.23	93.05	93.20
Volatile solids (%)	1	44.02	38.14	36.26	33.07	28.52	18.05
	2	39.89	41.21	35.45	37.56	36.12	15.92
Ammonia-N (mg/100g)	1	18.70	16.50	24.70	29.20	36.00	33.90
	2	7.90	10.30	14.50	15.00	13.40	17.20
Nitrate-N (mg/100g)	1	11.70	1.27	1.17	1.30	1.02	0.86
	2	3.53	3.90	2.77	3.73	4.70	4.17
Total nitrogen (%)	1	2.12	1.78	1.64	1.37	1.29	0.76
	2	1.92	1.76	1.64	1.63	1.55	0.65
Total phosphorous (%)	1	0.80	0.72	0.56	0.46	0.38	0.30
	2	0.71	0.53	0.47	0.58	0.54	0.23
Total potassium (mg/100g)	1	327.0	228.0	212.0	188.0	163.0	153.0
	2	242.0	213.0	197.0	190.0	190.0	160.0

Source: Ghosh et al. (1982).

Dry solids content increased with depth and thus with the age of the sludge. After ten years, the dry solids content had increased about tenfold. This increase was more marked in the sludge sampled near the inlet of the pond. The nature and dimensions of the particles which settle at each point can explain the differences which exist between the profiles near the inlet and near the outlet. Indeed, mineral solids (e.g. clay and silt) carried with the sewage and organic anthropogenic solids with larger dimensions settle preferentially near the inlet, whereas fine organic particles, among them many algae settle near the outlet.

The total organic carbon content (TOC) of the young sludge was very high at both points, and highest near the outlet. The profiles showed an important decrease in TOC content with depth and thus with time. This decrease was more important near the outlet. The deepest and thus the oldest sludges, which had residual TOC contents comparable to those of organic matter rich limnic and oceanic sediments lost 80% to 85% of their total carbon in 10 years. The differences between the two profiles was explained by the larger fraction of mineral solids carried in the raw sewage and settled near the inlet and by more rapid decomposition of the organic solids near the outlet as a result of:

- the higher porosity of the sludge at that point, offering a larger surface area for bacterial activity, and
- the algal ability to mineralise rapidly.

The measured pH values, slightly acid especially near the inlet, showed a tendency to increase with depth and with distance from the point near the inlet to the point near the outlet. The pH increase with depth might have been a result of the predominance of methanogenesis accompanied by the degradation of the initially produced volatile fatty acids. The higher pH of the sludge near the outlet can be explained by the nature of the compounds which accumulate there, that is anthropogenic particles resuspended from the pond elsewhere, and thus partially degraded, and algae, which decompose rapidly.

The analyses showed the existence of high Kjeldahl nitrogen concentrations in the sludge near the outlet, where the mineral lithogenic solids were less abundant, and which result from the organic nitrogen supplied by the raw sewage and from the sedimented algae. The particulate Kjeldhal nitrogen concentrations decreased with depth, whereas the dissolved ammonia concentrations in the interstitial phase increased and became very important, especially near the inlet. As noticed by several authors, this evolution reflects the mineralisation of the organic nitrogen which increases in rate over the long term. On the other hand, the redox potential in the sludge facilitates the solubilisation of ammonia. The difference between the particulate Kjeldahl nitrogen concentration of the superficial sludge (the young sludge) and the deeper sludge (the old sludge) corresponds to the regeneration of about 70% of the initially present nitrogen.

The results of Carre et al. (1987) showed the total phosphorus concentration in the sludge to be higher near the outlet of the ponds. At the inlet and outlet points, a decrease of the total phosphorus concentration with depth was observed and the difference between the concentrations of the superficial and the deep sediments corresponded with the regeneration of 75% of the originally present phosphorus.

2.3. Parasites

Parasites include protozoa, nematodes, and helminths. Pathogenic enteric protozoa are single-celled animals that range in size from 8μ to 25μ. Protozoa are transmitted as cysts, the non-active and environmentally insensitive form of the organism. Their life cycles require that a cyst be ingested by man or another host. The cyst is transformed into an active organism in the intestines, where it matures and reproduces, releasing cysts in the faeces. Pathogenic enteric protozoa are listed in **Table 2.7**, together with the diseases they cause.

Intestinal Nematodes are roundworms, hookworms and whipworms that may reach sizes up to 14 in. (36 cm) in the human intestines. The more common such worms found in man and the diseases they cause are also listed in Table 2.7. They may invade tissues other than the intestine. This situation is especially common when man ingests the ova of a round worm common to another species, such as the dog. The nematode does not stay in the intestine but migrates to other body tissues, such as the eye, and encysts. The cyst, similar to that formed by the protozoa, causes inflammation and fibrosis in the host tissue. Pathogenic nematodes cannot spread directly from man to man. The ova discharged in faeces must first embryonate at ambient temperature, usually in the soil, for at least two weeks.

Helminths also include flatworms, such as tapeworms, that may be more than 12 inches (30 cm) in length. In terms of population biology, helminth parasites have been defined as metazoan macroparasites, slower growing than microparasites such as viruses, bacteria and protozoa, with longer generation times, and with low-rate or no direct multiplication within the host. The most common types listed in Table 2.7, are associated with beef, pork and rats. Transmission occurs when man ingests raw or inadequately cooked meat or the eggs of the tapeworm. In the less serious form, the tapeworm develops in the intestine, maturing and releasing eggs. In the more serious form, it localises in the ear, eye, heart, or central nervous system.

2.3.1. Parasites Potentially of Concern to Public Health

The parasite ova most resistant to sludge treatment processes are those having thick shells capable of preventing penetration of toxic materials through the shells and which are resistant to temperature or other adverse environmental changes. According to Fox et al. (1981), these are the ova of the helminth belonging to the genera *Ascaris*, *Toxocara*, *Trichuris*, and *Taenia*. Researchers have observed that ova of the ascarid roundworms, for example, are most resistant to adverse environmental changes. It is reasonable to assume, that factors influencing the survival of these ova would also significantly affect the survival of less resistant forms. According to Barnard et al. (1987), Noble and Noble (1982) estimated that a total of 716 million humans worldwide were infected with *Ascaris*, with the rate of infection as high as 100% in some tropical areas. Barnard et al. (1987) mentioned that according to Muller (1979), many developed countries as well were highly infected with *Ascaris;* Surveys of children showed that 20 to 50% in Kentucky (USA), 18 to 40% in France, 21% in Spain, and 75% in Italy.

Table 2.7. Pathogenic Human & Animal Parasites Potentially in Sewage Sludge

Species	Disease
a. Protozoa	
Acanthamoeba species	Amoebic meningoencephalitis
Balantidium coli	Balantidiasis; Balantidial dysentery
Dientamoeba fragilis	Dientamoeba infection
Entamoeba histolytica	Amoebiasis; amoebic dysentery
Giardia lamblia	Giardiasis
Isospora bella	Coccidiosis
Naegieria fowleri	Amoebic meningoencephalitis
Toxoplasmosis	
Cryptosporidium	
b. Nematodes	
Ancylostoma diurodenale	Ancylostomiasis; hookworm disease
Ancylostoma species	Cutaneous larva migrans
Ascariasis lumbricoides	Ascaris; roundworm disease Ascaris pneumonia
Enterobius vermicularis	Oxyuriasis; pinworm disease
Necator americanus	Necatoriasis; hookworm disease
Strongyloides stercoralis	Strongyloidiasis; hookworm disease
Toxocara canis	Dog roundworm disease; visceral larva migrans
Trichuris trichiura	Trichuriasis; whipworm disease
c. Heminths	
Diphyllobothrium latum	Fish tapeworm disease
Echinococcus granulosus	Hydatid disease
Echinococcus multilocularis	Alveolar hydatid disease
Hymenolepis diminuta	Rat tapeworm disease
Hymenolepis nana	Dwarf tapeworm disease
Taenia saginata	Taeniasis; beef tapeworm disease
Taenia solium	Cysticercosis; pork tapeworm disease

Source: Cheremisinoff (1994).

Tapeworms, classed as cestodes, are one of the pathogens of major concern, in respect of the agricultural utilisation of sewage sludge. The tapeworm reaches maturity within about ten weeks, and can live in the human intestine for as long as 25 years.

Taenia saginata is the most common taeniid of man, the definitive host, and the adult tapeworm lives only in humans. *Taenia saginata* occurs in all countries where beef is eaten. *Taenia saginata* eggs are considered to lose viability and infectivity completely after six months in sludge or soil (Pike & Davis, 1984).

Ascaris lumbricoides is the most ubiquitous and most common of all parasites of man. The adult worm lives in the intestine with an estimated daily output of 200,000 eggs for each female worm. The life cycle is completed when, after a period of incubation, fertilised eggs are ingested. The ingested egg liberates a larva which migrates through the liver and lungs before reaching the intestine, its final destination.

The hookworms *Ancylostoma duodenale* and *Necator americanus* cause serious problems of human infection, especially in the tropics. Hookworm eggs are thin-shelled and much less resistant to adverse conditions than *Ascaris* eggs, so that treatment methods designed to inactivate *Ascaris* should also deal with hookworm eggs.

The nematode worm *Strongyloides stercoralis* has some similarities to the hookworms in that infection occurs by means of larvae in an infective form entering the human host through the skin, being carried to the heart and the lungs, passing up through the bronchial tubes and entering the digestive tract by being swallowed; the adult parasite then develops in the small intestine. Thenceforth, however, the life cycle of the parasite is much more complex and the result of infection is potentially more serious than in the case of the hookworms. *Strongyloides stercoralis* exists in sludge as a delicate larva, not as a robust egg, and it is to be expected that complete elimination will take place during most sludge treatment processes. *Strongyloides* eggs in sludge treatment processes may be eliminated in a manner similar to hookworm eggs.

The whipworm *Trichuris trichiura* infects the human host through the host's ingestion of mature, infective eggs in soil or contaminated food. The eggs hatch in the intestine, and the resultant larvae pass to the coecum where they mature into male or female adults. Female worms produce up to 10,000 eggs daily, which pass out with faeces and mature into an infective form in soil. *Trichuris* eggs can survive over three months at 25°C in clay soil with manure.

The pinworm or threadworm *Enterobius* is the most widely distributed nematode infection, especially in children. The eggs are not normally excreted in faeces and infection can be passed directly from person to person without the eggs needing to develop in soil. It is also more common in temperate climates than in warm climates and is relatively rare in the tropics, unlike most helminthic infections. *Enterobius* eggs are more rapidly killed by hostile environmental factors (especially heat and desiccation) than are *Ascaris* eggs, and they will be eliminated from night soil and sludge long before *Ascaris* eggs.

The ascarid worms *Toxocara canis* and *T. cati* occur throughout the world in domestic and wild canines and felines. Eggs passed in dog or cat faeces develop to an infective stage after about two weeks, and can persist for as long as four years. According to Cheremisinoff (1994), reported data give *Toxocara* survival as eight months at 25°C and two years at 4°C in clay soil and manure.

2.3.2. Indicator of Parasites in Sludge

Of the human parasites, the eggs of *Ascaris* species are the ones that are most commonly found in raw and stabilised sludges and are probably the most important. *Ascaris* eggs are resistant to a wide range of chemical and physical conditions and are generally considered to be the most resistant form of any parasite.

According to Hillel et al. (1981), Keller (1951) stated that the extraordinary power of resistance of *Ascaris* ova to changes in temperatures and moisture concentrations and to chemical influences is due mainly to the complicated structure of the egg shell. The egg shell consists of 5 layers, namely, an outer proteinacious membrane and 3 layers of schitinous material and an inner lipoidal membrane. The outer albuminous coat is partially coagulated and hardened by certain hostile factors. The thick shell of the *Ascaris* egg and the ability of the larvae to become metabolically inactive when they reach the infective stage, are factors put forward to explain their great longevity; survival periods recorded range from 11 months to 5 years.

O'Donnell et al. (1984) performed a large study on the destruction rates of *Ascaris* eggs in sludge lagoons. After 33 months, more than 50% of the *Ascaris* eggs recovered from the samples kept at 4°C were still viable. However, 10 to 16 months of storage at 25°C were sufficient to render most of the recovered eggs nonviable.

For these reasons, it has been proposed that in areas where Ascariasis is endemic, if there are no viable *Ascaris* ova present in sewage sludge, then other pathogens are absent as well. Moreover, *Ascaris lumbricoides* has been considered as the standard by which the safety of sludge disinfection measures and agricultural applications are assessed (Steer et al. (1974); Hannan (1981); Hillel et al. (1981); Feachem et al. (1983); Reimers et al. (1986); and Smith (1996)).

2.3.3. Survival of Parasites in Sewage Sludge

The numbers and types of parasites present in sewage sludge are primarily influenced by the infection rate of the local population. The literature survey showed that little data about the densities of parasites were recorded for waste stabilisation pond sludge (Table 2.4). However, other sludges (from primary clarifiers, activated sludge and extended aeration units, etc.) have been analysed for parasites and referred to in the literature. **Table 2.8** shows the levels of helminth eggs in raw sludges from different countries.

Table 2.8. Levels of Helminth Eggs in Raw Sewage Sludges Recorded in Different Countries

Counts (range)	Unit	Type of Parasite	Country	Reference
14,000-25,000	eggs/g wet weight	*Ascaris*	Iran	Sadighian et al. (1976)[a]
60	eggs/kg wet weight	*Ascaris, Trichuris*	USSR	Asvin and Lagutina (1976)[a]
287-1943	eggs/100 g dry weight	*Ascaris, Trichuris*	Southern US	Reimers et al. (1983)
5,187-44,306	eggs/g dry weight	-	Brazil	Ayres (1992)
83-130	eggs/g dry weight	-	France (Nancy)	Schwartzbrod et al. (1986)[b]
225-325	eggs/100g wet weight	-	Marrakech	Schwartzbrod et al. (1987)[b]

[a] Cited by Reimers et al. (1983).

[b] Cited by Hindiyeh (1995).

Reimers et al. (1983) carried out field studies for a year on parasites in domestic waste sludges in the Southern states of the US. This investigation resulted in new information concerning the types and concentrations of resistant stages of parasites in southern domestic sludge. According to Reimers et al. (1983), the total number of parasite eggs recovered from sludge samples in all plants ranged from 0 to more than 230,000 eggs/kg dry weight of sludge, depending on the parasites involved, source of sludge and specific season. The average number of total parasite eggs present was found to be approximately 14,000/kg dry weight of sludge. The percentage of viable parasite eggs in each sample was generally greater than 45%. Even though the concentration of total parasite eggs fluctuated over a wide range, observations can be made as to the number of specific parasites which can be expected for any given sludge, as demonstrated in **Table 2.9**. Other parasite eggs and cysts were observed in the sludge samples, but in low concentrations.

Table 2.9. Parasite Concentrations in Primary, Secondary and Treated Sewage Sludge

Parasite	Nature of sludge*	Average number of eggs/kg dry weight of sample	Viable eggs (%)
Ascaris species (human & pig roundworm)	Primary and secondary Treated	9,700 9,600	45 69
Trichuris trichiura (human whipworm)	Primary and secondary Treated	800 2,600	50 48
Trichuris vulpis (dog whipworm)	Primary and secondary Treated	600 700	90 64
Toxocara species (dog & cat roundworm)	Primary and secondary Treated	1,200 700	88 52

Source: Reimers et al. (1983).

* Primary and secondary sewage sludges include sludges from primary clarification, Imhoff digestion, activated sludge, contact stabilisation, and extended aeration. Treated sludges include sludges from mesophilic aerobic and anaerobic digestion, vacuum filtration, centrifugation, lagoons and drying beds.

It appears that the levels of helminth eggs in Southern US sewage sludges are, in general, lower than those that have recently been reported for other countries, although the sludges from a few of the southern US sewage treatment plants had comparable levels (see Table 2.8).

The study carried out by Reimers et al. (1983) allows a very important conclusion. Through the data shown in Table 2.9, it is clear that not only *Ascaris* but also *Trichuris T., Trichuris vulpis* and *Toxocara* species are quiet resistant to sludge treatment processes and represent a potential health risk to man. This fact has also been referred to by Fox et al. (1981).

2.4. Regulations & Guidelines on Sludge Quality for Agricultural Utilisation

The use of sewage sludge on agricultural land has become increasingly popular due to the fact that it contains valuable agronomic properties. However, it must be realised that sewage sludge contains a great variety of pathogenic microorganisms in relatively high numbers and that its use on land can intensify infection transmission cycles. Sludge can also contain heavy metals and other compounds at toxic concentrations. These compounds might be toxic to the plants and suppress growth, or the plant may concentrate the toxin and present a health hazard to people or animals. However, this research is dealing with parasites and, accordingly, only brief information will be given concerning heavy metals and other pollutants.

Several countries have issued directives and suggested treatment processes in order to effect a substantial reduction in the concentration of pathogens in sewage sludge before it is allowed to come into contact with land, as well as suggesting the application and use of sewage sludge on land. However, such regulations and guidelines issued by different countries vary from one to another due to several reasons; most important of all are pathogen types present and their concentrations, climate, soil characteristics and economic status of the country. The regulations have been set out after extensive research work; for example it took 11 years for the USEPA to formulate the federal regulations for the use and disposal of biosolids (WRC, 1999).

2.4.1. International Sludge Regulations

WHO (1989) considered the human and animal risks from pathogens in sewage and sewage sludge applied to land and issued guidelines for enforcing adequate control measures. If the waste products are not buried in trenches but are applied as a topsoil dressing (as is common with composts, for instance), or if they are regularly applied to the soil after planting has occurred, the WHO guidelines for wastewater irrigation should be observed, and interpreted as <1 egg per litre or 100g (wet weight) and <1000 faecal coliforms per 100ml or 100g (wet weight) as appropriate. Treatment of nightsoil to achieve the helminth standard for restricted use can be achieved by various technologies and, according to WHO (1989), composting is an effective way to achieve the standards for unrestricted use.

Guidelines for sewage sludge application on land meeting the UK standards are given in the Code of Practice for Agricultural Use of Sewage Sludge (Department of Environment, 1989). The code is designed to ensure that when sludge is used in agriculture:

- There is no conflict with good agricultural practice.
- The long term viability of agricultural activities is maintained.
- Public nuisance and water pollution is avoided.
- Human, animal or plant health is not put at risk.

Except when it is to be injected or otherwise worked into the soil so as not to cause nuisance, sludge must be subjected to biological, chemical or heat treatment, long-term storage or any other appropriate process so as to significantly reduce its fermentability and health hazards resulting from its use before being used in agriculture in the UK. According to the Department of Environment (1989), examples of treatment processes which will satisfy these requirements are listed in **Table 2.10.** In this context, the contents of septic tanks and sludges from secondary biological treatment, such as humus sludge, surplus activated sludge and residual sludge from extended aeration plants, cannot be considered to be biologically treated.

However, the UK Government has published recently the waste strategy, which sets out the need for a substantial increase in recycling and composting, in order to develop a more sustainable waste management system. According to Wilkins (2000), the UK Government is aiming to increase the household recycling and composting to at least 30% by 2010. The Composting Association conducted a feasibility study in 1998, which included standards for both the composting process and the quality of the final compost, and by May 2000 the standards for composts were issued (Wilkins, 2000). The standards specify certain concentration limits for selected Potentially Toxic Elements (PTEs), physical contaminants (such as glass, plastic, metal, etc.), human pathogens, weed seeds, as well as the presence of substances toxic to plants. Moreover, some information should be provided on the packaging and/or documentation accompanying the final product, including compost characteristics, such as pH, total nitrogen, particle size grading, and more. Some other characteristics were optional, which included phosphorus, potassium, secondary nutrients and trace elements required by plants.

The development and application of sludge management and control in Europe and the United States are summarised below, with particular emphasis on the beneficial use of sludge on land. Probably the largest risk assessment in the field of environmental protection was conducted by the United States Environmental Protection Agency (USEPA) to formulate the federal regulations for the use and disposal of biosolids (WRC, 1999). This involved an 11 year programme and cost US$15 million. It was completed in 1992, 6 years after publication of the European Community (EC) Directive and hence the EPA had access to a far larger body of relevant experimental data on which to base its legislation. The US regulations are known as Part 503 of the Clean Water Act or 40 CFR. **Table 2.11** shows the sludge quality limits in the US and the EC, for the potentially toxic elements (PTEs).

The USEPA regulations refer to "ceiling limits" and "exceptional quality". If sludge exceeds the ceiling limit for any element, it is considered to be too polluted for beneficial use and must be disposed of by incineration or landfill. If a sludge is below the exceptional quality limits, and if it satisfies the Class A pathogen standards described below, it can be sold or given away without any monitoring or control, except for advice on the application rate. For sludge falling between the two limits, they can only be used on "permitted" sites.

Table 2.10. UK Department of the Environment Code of Practice for Sludge Reuse for Agricultural Purposes

Process	Descriptions
Sludge pasteurisation	Minimum of 30 min. at 70°C or minimum of 4 hr at 55°C (or appropriate intermediate conditions), followed in all cases by primary mesophilic anaerobic digestion.
Mesophilic anaerobic digestion	Mean retention period of at least 12 days primary digestion in temperature range 35°C +/- 3°C or of at least 20 days primary digestion in temperature range 25°C +/- 3°C followed in each case by a secondary stage which provides a mean retention period of at least 14 days.
Thermophilic Aerobic Digestion	Mean retention period of at least 7 days digestion. All sludge to be subject to a minimum of 55°C for a period of at least 4 hr.
Composting (windrows or aerated piles)	The compost must be maintained at 40°C for at least 5 days and for 4 hr. during this period at a minimum of 55°C within the body of the pile followed by a period of maturation adequate to ensure that the compost reaction is substantially complete.
Lime stabilisation of liquid sludge	Addition of lime to raise pH to greater than 12.0 and sufficient to ensure that the pH is not less than 12 for a minimum period of 2 hr. The sludge can then be used directly.
Liquid storage.	Storage of untreated liquid sludge for a minimum period of 3 months.
Dewatering and storage.	Conditioning of untreated sludge with lime or other coagulants followed by dewatering and storage of the cake for a minimum period of 3 months. If sludge has been subject to primary mesophilic anaerobic digestion, storage to be for a minimum period of 14 days.

Source: Department of Environment (1989).

Table 2.11. Comparison of Sludge Quality Limits Regarding Potentially Toxic Elements Concentrations (mg/kg dry solids) in US & EC Standards

PTE	EC Directive 86/278/EEC		USEPA Part 503	
	Lower limit	Upper Limit	Exceptional quality*	Ceiling concentration
Zinc	2500	4000	2800	7500
Copper	1000	1750	1500	4300
Nickel	300	400	420	420
Cadmium	20	40	39	85
Lead	750	1200	300	840
Mercury	16	25	17	57
Chromium	-	-	1200	3000
Molybdenum	-	-	18	75
Selenium	-	-	36	100
Arsenic	-	-	41	75

Source: WRC (1999).

* Limit values adopted in Egyptian Decree 214/1997.

The Part 503 regulations classify sewage sludge into two categories, **Class A** (exceptional quality) and **Class B** (ceiling concentration). All sewage sludge that is land applied must meet at least class B requirements. Bulk sewage sludge that is land applied to lawns and home gardens and sewage sludge that is sold or given away in bags or other containers must meet the Class A criteria and one of the vector attraction reduction options. The USEPA rule also imposes "Vector Reduction" requirements, i.e. management practices that reduce the attraction of insects, animals, etc. **Table 2.12** compares the sludge treatment requirements of USEPA with those in the UK.

Table 2.12. Comparison of US (USEPA 1993) and UK Criteria (DoE 1996) for Pathogen Reduction Meeting the PSRP & PFRP

Process	US Regulations	UK Code of Practice
a. Processes to significantly reduce pathogens (PSRP):		
Aerobic digestion	49 d at 20°C to 60 d at 15°C	Not recognised
Drying beds, dewatering and storage	3 months (or 2 months above 0°C)	3 months, if anaerobically digested 14 d
Composting	40°C or higher for 5 d (over 4 hr. exceeding 55°C)	40°C or higher for 5 d (over 4 hr. exceeding 55°C)
Anaerobic digestion	15 d MRT at 35-55°C, or 60 d at 20°C.	12 d MRT at 35±3°C; or 20 d at 25°C±3°C; both followed by secondary digestion, 14 d MRT
Liquid storage	Not recognised	3 months
b. Processes to further reduce pathogens (PFRP):		
Composting	Within vessel, 3 d at 55°C; Windrows, 15 d at 55°C	5 d at 40°C or higher (exceeding 55°C for >4 h)
Drying	80°C in sludge or exhaust gas	Not recognised
Heat	180°C for 30 min.	Not recognised
Thermophilic aerobic digestion	10 d MRT at 55°C	7 d MRT, with at least 55°C for 4 hr.
Pasteurisation	70°C for 30 min.	70°C for 30 min., or 55°C for 4 hr.
Lime stabilisation	pH 12 for 2 hr.	pH exceeding 12 for 2 hr.

Source: WRC (1999).
MRT: Mean residence time

EPA Class A Sewage Sludge (Outwater, 1994):

Class A sludge must meet one of the following criteria:

1. A faecal coliform density of less than 1000 MPN/g total dry solids (TS) **or**;
2. A Salmonella species density of less than 3 MPN/4 g TS **and**;

the requirements of **one** of the following alternatives must be met:

a. **Time/temperature-** An increased sewage sludge temperature should be maintained for a prescribed period of time according to the guidelines shown in **Table 2.13 or;**

b. **Alkaline treatment-** The pH of the sewage sludge must be raised to greater than 12 for at least 72 h. During this time, the temperature of the sewage sludge shall be greater than 52°C for at least 12 h. In addition, after the 72 h period, the sewage sludge is to be air dried to at least 50% TS **or;**

Table 2.13. Time and Temperature Guidelines for Treatment of Sludge to EPA Class A Standard

Total solids	Temperature (°C)	Time (min.)	Notes
≥ 7%	≥ 50°C	≥ 20 min.	No heating of small particles by warmed gases or immiscible liquid.
≥ 7%	≥ 50°C	≥ 15 s	Small particles heated by warmed immiscible liquid.
≥ 7%	≥ 50°C	≥ 15 s to < 30 min.	
≥ 7%	≥ 50°C	≥ 30 min.	

Source: Outwater (1994).

c. **Prior testing for enteric viruses/viable helminth ova-** If the sludge is analysed before the pathogen reduction process and found to have densities of enteric viruses < 1 plaque forming unit (pfu) per 4 g total solids (TS) and <1 viable helminth ovum per 4 g TS, the sludge is Class A with respect to enteric viruses and viable helminth ova until the next monitoring session.

d. **Testing for enteric viruses/viable helminth ova after treatment-** The sludge must meet the enteric virus and viable helminth ova levels noted below to be class A at the time the sludge is used or disposed of, prepared for sale, or given away in bag or container, or when the sewage sludge or derived material meets "exceptional quality" requirements- pollutant concentration limits, class A pathogen reduction, and vector attraction reduction requirements:

  - The density of enteric viruses must be <1 pfu/4 g TS.
  - The density of viable helminth ova must be <1 per 4 g TS, **or**

e. The sewage sludge is treated by a Process to further Reduce Pathogens (PFRP) as shown in Table 2.12.

EPA Class B Sewage Sludge (Outwater, 1994):

Class B sludge must meet one of the following pathogen reduction requirements:

1. The sewage sludge must be treated with a Process to Significantly Reduce Pathogens (PSRP), as shown in Table 2.12; **or**
2. At least seven sewage sludge samples should be collected at the time of use or disposal and analysed for faecal coliforms during each monitoring period. The geometric mean of the densities of these samples will be calculated and should meet the following criteria:
   a. < 2 million MPN/g TS; **or**
   b. < 2 million cfu/g TS

In addition, for any land-applied sludge that meets class B pathogen reduction requirements, but not those of Class A, additional site restrictions shall be observed.

Accordingly, as shown in **Table 2.14**, sludge treated using PFRP specifications can be used for a greater variety of applications.

Table 2.14. Summary of US Federal Restrictions on Use of Sludge Products

Process	Public access	Grazing limitations	Crops Grown for Human Consumption	
			Contact between edible portion & sludge	No contact between edible portion & sludge
PFRP Class A)	No control required	No limitation	Crops permitted	Crops permitted
PSRP (Class B)	Controlled for 12 months following application	No grazing for 1 month following application	No crops permitted for 18 months following application	Crops permitted

Source: WPCF (1985).

Under USEPA regulations, regular monitoring is also compulsory for ensuring the final sludge quality before land use. The minimum frequency of monitoring for metals, indicator organisms, and vector attraction reduction requirements shall be based on the amount of sewage sludge produced annually, as shown in **Table 2.15**, although more frequent monitoring requirements may be imposed by the permitting authority. After a period of 2 years, the permitting authority may allow the monitoring frequency to be reduced to no less than once a year. In general, records must be kept for 5 years.

Table 2.15. USEPA Monitoring Frequency

Sewage sludge amounts (dry metric tons / year)	Monitoring frequency
>0 to <290	Once per year
290 to <1,500	Once per quarter
1,500 to <15,000	Once per 60 days
≥15,000	Once per month

Source: WRC (1999)

However, it is important to mention that the current EC directive has been under revision, and is in the Consultation stage. It is expected to be enforced very soon, and focuses mainly on protecting the soil and reducing the risk of disease transmission to humans and animals from the recycling of sewage sludge operations. The European Commission working document on Sludge 3rd Draft (2000) has been stressing, in general, in the control of PTEs by prevention at source because process technology to remove them from sewage sludge would be both expensive and difficult to achieve. The major changes that have been stated in the revised draft directive include specific concentrations of heavy metals in soils, classified according to the soil pH, as shown in **Table 2.16**. These will control the amounts of sludge which can be applied to land depending on heavy metal levels in the sludge. Also introduced are new minimum standards for time/temperature and pH/time/temperature, which must be achieved by approved processes. These will apply to both "Advanced Treatment Processes" and "Conventional Processes". The concept of "Producer Responsibility and Certification" is also introduced, which will require producers to implement a Quality Assurance System for the whole sludge process. Moreover, the significant sampling points at which measurements should be taken in order to verify the suitability of sludge are defined.

Table 2.16. Proposed Limit Values for Concentrations of PTEs in soil (mg/kg DS)

Element	Directive 86/278/EEC 6<pH<7	5≤pH<6	6≤pH<7	pH≥7
Cadmium	1-3	0.5	1	1.5
Chromium	-	30	60	100
Copper	50-140	20	50	100
Mercury	1-1.5	0.1	0.5	1
Nickel	30-75	15	70	70
Lead	50-300	70	150	100
Zinc	150-300	60		200

Source: Working Document on Sludge (2000)

2.4.2. Egyptian Sludge Regulations

During 1993, the Cairo Wastewater Organisation (CWO) and the European Investment Bank (EIB) initiated a programme to assess the reuse of sewage sludge in Cairo as an organic fertiliser through the assessment of actual application of various kinds of sludge to different types of agricultural soil. This study has been overseen by a steering committee representing all the concerned environmental authorities, including the National Organisation for Potable Water & Sanitary Drainage (NOPWASD), the Egyptian Environmental Affairs Agency (EEAA), the National Research Centre (NRC), and others.

The principal objective of the Cairo Sludge Disposal Study was to provide scientifically sound and practical advice to sludge producers, environmental and health protection authorities and farmers for the sustainable and safe use of sewage sludge in agriculture on a large scale in Egypt. The study was also designed to serve as a demonstration programme and information source for other similar towns and cities in Egypt. Based on the results of this programme, the Egyptian Sludge Regulations would be issued.

The study has been carried out in three phases over 45 months. Phase 1 (3 months) was a review and planning stage, involving a worldwide survey of information, and the development of sludge sampling and field trials programmes to be carried out over three years during Phase 2. During Phase 3, three key outputs have been produced: scientific reports of the findings of Phase 2, a farmers guide to the practical use of sludge, and the issuance of the Egyptian Sludge Regulations (Decree 214/1997); Processing and Safe Use of Sludge. The US regulations (40 CFR, Clean Water Act, Part 503, 1993) have been adopted as the basis for the Egyptian sludge regulations (Decree 214/1997), since these standards are the most recent. The key component of the recommended sludge reuse strategy is to produce biosolids that are safe for uncontrolled use.

According to Decree 214 for the year 1997, sludge allowed to be re-used in agriculture should conform to the following:

1. Concentrations of heavy metals (dry solids basis) should not exceed the limits shown in **Table 2.17.**
2. Content of pathogens should not exceed the following limits:
   a. Faecal coliform MPN should be less than 1000 cells per 1 g dry solids. *Salmonella* MPN should be less than 3 cells per 100 ml at a sludge concentration of 4% dry solids.
   b. Virus (intestinal): 1 unit per 100 ml at a sludge concentration of 5% dry solids.
   c. Worm ova (*Ascaris*): 1 ovum per 100 ml at a sludge concentration of 5% of dry solids. More than 3 species of ova are not allowed.

Sludge producers should take into consideration the conformity of sludge sold to be reused in agriculture with the standards described previously, by stabilising the sludge with one of the following safe methods:

- Aerobic digestion
- Anaerobic digestion
- Thermal treatment
- Lime addition
- Composting

Table 2.17. Concentrations of Heavy Metals in Sludge Allowed for Agricultural Purposes in Egypt

Pollutant	Concentration limit (safe sludge) mg/kg dry solids
Zinc	2800
Copper	1500
Nickel	420
Cadmium	39
Lead	300
Mercury	17
Chromium	1200
Molybdenum	18
Selenium	36
Arsenic	41

Source: WRC (1999).

A simple economic technology can be applied for composting the sludge by adding and mixing one of the following materials:

- Quicklime
- Cement dust
- Primary processed domestic refuse
- Organic plant wastes such as wood shavings, straw, hay, peanut husk, etc.

Collecting and analysing samples should be conducted on regular basis, but this is not specified in the Egyptian Regulations. If the heavy metals content and/or pathogens in the sludge exceed the standard levels provided in Decree 214 for the year 1997, the sale of the whole quantity of sludge from which the sample was taken will be prevented. Sludge should then be buried according to hygienic specifications or burned in incinerators provided that the produced gas shall be clean, taking in consideration all environmental precautions.

2.5. Drying Beds

Sludge treatment and safe disposal is one of the major problems confronting wastewater treatment facilities, from both the technical and economic points of view. This problem is especially crucial for small treatment works, as small amounts of sludge are produced and an equivalent mechanical dewatering system would require relatively high initial cost compared to the size of the treatment plant. In such cases, drying beds are especially popular and, hot climates are favourable for this type of natural dewatering system. According to El-Ariny et al. (1984), approximately two-thirds of all the wastewater treatment plants in the US utilise drying beds for the dewatering of sewage sludge.

They consist simply of shallow ponds containing sand and gravel and equipped with underdrains. Sludge is pumped onto the beds to a depth of 150-300 mm and the time required for the sludge to dewater to a liftable consistency ranges from several weeks to several months. The layout and construction of drying beds are variable, mainly influenced by the method of removal of cake (by hand or machine).

Water removal is achieved through several processes that are interrelated. Basically drainage and evaporation contribute to the removal process of water. Some research work has been carried out on the efficiency of drying beds to inactivate parasites, however, the relation between the sludge layers depths, solids content and parasites inactivation was not studied.

2.5.1. Mechanisms of the Drying Bed Process

When sludge is first applied to a drying bed, the rate of drainage is normally rapid over the first 1 to 3 days. During the next two or three days the rate progressively decreases, partly because of solid matter which becomes compacted on the surface of the media, offering resistance to filtration. Following the removal of supernatant liquor by drainage, evaporation becomes important and, during the initial stages of dewatering, the rate of evaporation is similar to that from a free water surface.

Evaporation is affected by weather conditions, including air temperature, humidity, sun intensity and wind conditions.

Eventually, a stage is reached in the dewatering process when the sludge starts to crack and as these cracks extend deeper into the layer of sludge the surface exposed to evaporation increases. When the cracks extend to the surface of the underlying media, rain falling on the sludge drains through, so that dewatering is no longer affected to any great extent by rainfall. This is normally the earliest stage at which the sludge is liftable.

According to Pescod (1971), pilot scale studies carried out by Luong and Tseng on sand beds had shown that the combination of drainage and evaporation is highly effective for dewatering. It was observed during the wet season in Thailand that if precipitation occurred before free water in the sludge had drained, the moisture content of the sludge increased and the drainage time was prolonged. If, however, sludge surface cracking caused by evaporative drying was deep enough to expose the sand medium, rainfall would pass straight through the sludge and drain directly, causing increases in drainage volume and rate.

2.5.2. Factors Affecting Sludge Drying Bed Performance

When liquid sludge is applied to a drying bed, dewatering takes place partly by drainage and partly by evaporation as discussed in Section 2.5.1. The proportions in which liquor is removed and pathogens are reduced by each of these ways, and the efficiency of the process as a whole, depends upon the following factors:

i. **Nature of sludge:** According to the Manulas of British Practice in Water Pollution Control (1981), raw sewage sludges, and especially those containing a high amount of grease, tend to dry only slowly by evaporation above a dry solids content of about 30% but digested sludges normally crack more readily forming a highly fragmented cake which, in suitable weather, will dry to a total solids content as high as 70%. Digested sludge usually drains readily, leaving a cake of relatively uniform dry solids content but raw sludge drains slowly, leaving a cake which is wet and sticky in the lower layers with a hardened surface crust. Sand drying beds are usually restricted to digested sludge because raw sludge is odorous, attracts insects, and does not dry well when applied at reasonable depths. The oil and grease associated with raw sludge clog the sand bed and impede drainage. According to Hossam et al. (1990), an experimental study was conducted to assess the drainability of sludge generated by different treatment processes (digested primary sludge and raw sludge) on sand drying beds located in Alexandria Eastern sewage treatment plant, Egypt. Digested primary sludge took 6 days to drain off and the drainage volume was 80% of the sludge volume, while a sample of raw primary sludge took 13 days to drain off 53% of the sludge volume.

ii. **Initial solids content:** It is preferable to consolidate or thicken the sludge as much as possible before application to drying beds in order to reduce the proportion of liquor which has to be removed by drainage. However, the solids content must not be so high that the sludge will not flow to all parts of the bed or be of an uneven thickness when dry. According to Pescod (1971), the studies carried out by Luong and Tseng showed that during the dry season in Thailand, sludge with low initial solids content drained faster, and most water was removed by drainage. Sludge with high initial solids levels took longer to drain, and evaporation then became more significant. In the wet season, when precipitation prolonged the drainage time, evaporation was significant regardless of the applied sludge solids content.

iii. **Depth of application:** Luong and Tseng (Pescod, 1971) investigated the effect of sludge application depth on sludge drying time to reach a liftable condition. For any particular sludge dried under the same weather conditions, an increase in dosing depth of 10 cm increased the necessary drying time by 50 to 100%. According to the Manuals of British Practice in Water Pollution Control (1981), the depth to which sludge is applied varies between 150 mm and 350 mm. With mechanically lifted beds the depth of application is often 200 mm. If the application is too shallow, the thickness of the sludge layer when dry will be small and more applications will be required to deal with a given volume of sludge. The number of applications normally varies from 3 to 5 per annum but more can be achieved using thinner applications on mechanically lifted beds.

iv. **Condition of drainage medium:** Drainage of liquor from the sludge is affected by the condition and grading of the medium and the effectiveness of the drainage system. If drainage is hindered, a greater proportion of the liquor has to be removed by evaporation.

v. **Weather conditions:** Pescod (1971) recommended drying beds for application in a tropical climate, since it is advantageous to both the drainage and evaporative phases of water removal. The drying time is shorter in regions of greater sunshine, low rainfall and low humidity. The prevalence and velocity of wind also affect evaporation rates from sludge beds. In addition, rainfall has a considerable effect on dewatering, especially before cracking. According to El-Ariny et al. (1984), a study was carried out in New Orleans, Louisiana Metropolitan area, during winter and summer seasons in order to study the effect of weather conditions on the drying process and solids content. With an average initial total solids (T.S.) content of 6.32%, the drying period required to reach 30%, 40% and 60% total solids during the winter season was 9, 18, 46 days, respectively, while the 90% T.S. were unattainable. During the summer season, 7, 10 and 20 days were the equivalent periods, while still the 90% total solids was unattainable. An average saving of around 50% of the drying time period was achieved during the summer season, compared to the winter climate.

As a conclusion, the level of solids encountered in the cake and the resultant levels of pathogenic and indicator organisms after drying are affected by the above mentioned factors and other variables. All factors are interrelated, and this explains the fact that drying beds performance, and presumably pathogens inactivation, is inconsistent and varies from one country to another.

The next section will review data available in the literature on the effect of drying beds and their operating parameters on the inactivation of parasites.

2.5.3. Effect on Parasites

The effect of drying beds on the fate of parasites is very well established and discussed in the literature. Time, temperature and desiccation are referred to as the principal lethal factors acting on parasites and pathogens in general. As discussed in Section 2.3.2, *Ascaris* are considered to be the most persistent helminth eggs, which survive under most harsh conditions. Accordingly complete inactivation of these organisms indicates the complete destruction of all pathogens in sludge.

Cram (1943) studied the survival of helminth ova and protozoan cysts in sludge. From observations on 17 lots of sludge, cysts were still viable after 12 days at 21°C, 10 days at 30°C. *Ascaris* eggs survived long periods of sludge drying; they were viable for as long as 118 days of indoor greenhouse drying and 170 days of outdoor drying. They were resistant to loss of moisture, with viable eggs being found in several sludge cakes with moisture content below 10%. In one lot of sludge, the cake still contained viable eggs when its moisture content was 5.8% after 81 days of drying at summer temperatures, which frequently reached 42°C in the greenhouse. However, in cakes with 3 and 4 % moisture, only disintegrated *Ascaris* eggs were found.

Cram at al. (1944) studied the difference between indoor and outdoor drying on parasites and moisture content. Six lots of digested sludge, containing *Ascaris* eggs, were dried in the greenhouse. The period of digestion, the chemical analysis of the sludge when poured, details concerning the drying bed, and the results of drying are shown in **Table 2.18**. The first 3 lots (nos. 7,2 and 4) were poured into a total of 8 compartments to evaluate differences in depth of gravel, sand and sludge. No *Ascaris* eggs appeared in the effluent from compartments having a 6 inch sand layer, whereas considerable numbers passed a 2 inch layer and small numbers passed a 4 inch layer. These cakes were dried during the summer months when the temperature in the greenhouse was frequently above 38°C, with a maximum of 46°C. Eggs in the upper layers embryonated as aerobic conditions prevailed. As noted in Table 2.18, the ova were extremely resistant to drying; 6 of the 8 cakes were removed after 18 to 81 days drying, while viability was still present, and the moisture content of these cakes was found to range from 5.8 to 11.5%. Two cakes held until the ova were non-viable proved to have a moisture content of 3.3 and 4.2% after 79 and 78 days of respective drying. The remaining 3 lots of sludge dried in the greenhouse were held for longer periods, extending into the winter. During this time the temperature fell below freezing more than one-third of the time. Nevertheless, 25% of the eggs were viable after 104 days in one cake with final moisture content 7.9% and 6% of the eggs in the other two cakes were viable after 118 and 107 days, with final moisture content somewhat above 50%.

For comparison with indoor drying, where the drop in moisture content was progressive but where direct sunlight was absent, 13 cakes of drying sludge were exposed to the elements on a porch roof. The moisture content varied greatly with the weather; when determinations were made in comparatively dry periods it ranged from 30 to 58%. In only 3 of the 13 cakes was there failure to find viable ova at the end of the observation period.

Information concerning the digestion and drying periods and the findings according to Cram et al. (1944) as regards persistence of viability of *Ascaris* eggs is presented in **Table 2.19**. Cram and Hicks concluded that during indoor drying where the drop in moisture content was progressive, but where direct sunlight was absent, *Ascaris* eggs survived drying to a point where the moisture content of the sludge reached 5.8% but failed to survive when moisture content reached a lower figure. Nevertheless, it is clear from the preponderance of positive findings that *Ascaris* eggs can survive long periods of digestion and drying of sludge.

Bhaskaran et al. (1956) performed laboratory experiments to determine the effect of time and desiccation on the survival of parasites. The results obtained are presented in **Table 2.20** and show that the parasites survived up to 51 days when the moisture content in the samples was 3.1%. The viability of the parasites was reduced to 10%, however, when the moisture content dropped to this level. According to this experiment, if drying has to be used as a method of destruction of parasites in sludge it is necessary to dry sludge to a very low level of moisture, which is not practicable.

According to Hays (1977), Rudolfs et al. (1951) mentioned that *Ascaris* eggs were totally inhibited when subjected to sun and dryness, however no data were presented. Hannan (1981) suggested that desiccation is the most lethal condition for eggs. When exposed to direct sunlight they are killed within a few weeks and under conditions of bright sunlight and desiccation in one to two hours.

Hillel et al. (1981) mentioned that Hogg (1950) studied the destruction of ova and cysts in digested sludge as a result of sun drying in thin layers of 2.5-15 cm. While sun dried sludge in 2.5-5 cm layers was found to be free of viable *Ascaris* eggs, examination of the 8-10 cm layers still showed the presence of viable *Ascaris* ova, although their numbers were very much reduced. From these results it would appear that sun drying of sludge in relatively thin layers for long periods is effective in destroying *Ascaris* ova.

According to Feachem et al. (1983) the suitable time-temperature conditions for the destruction of *Ascaris* eggs are as follows:

- at least 62°C for 1 hour.
- at least 50°C for 1 day.
- at least 46°C for 1 week.
- at least 43°C for 1 month.
- at least 42°C for 1 year.

The effect of time on the viability of *Ascaris* ova is different. According to Pedersen (1981), Keller and Hide (1951) performed research work on sludge with 1538 to 4564 viable ova/gram dry weight that had been dried for 1 to 42 days to a maximum solids content of 47.75%. Viable ova were discovered in a sample dried for an indeterminate length of time to a solids content of 95.6%. No conclusions were made as to the relationship between solids content and viability. However, the authors concluded that, based on the irregularity of numbers of viable ova recovered versus length of drying time, there was no direct correlation between duration of drying time and the relative viability of ova recovered.

Table 2.18. Effect of Sludge Drying at Varying Temperatures in a Greenhouse on *Ascaris* Eggs

Lot No.	Digestion		Sludge (%)		Bed dimensions			Days drying	Viability (% if known)	Drying temperature (^{0}F)				% moisture
	Days	Temp (^{0}F)	Solids	Ash	Gravel (in.)	Sand (in.)	Sludge (in.)			Max.	Min.	Days (70 or over)	Days (32 or below)	
7	53	86	1.8	54.1	12	2	6	18	+	112	60	18	0	6.8
					9	2	9	51	+	115	56	51	0	6.8
					6	2	12	79	-	115	52	79	0	3.3
2	88	86	3.7	37.7	8	6	6	35	+	115	60	35	0	10.6
					5	6	9	51	+	115	56	51	0	11.5
					2	6	12	81	+	115	56	81	0	5.8
4	133	86	7.9	25.8	8	6	6	78	+	112	36	67	0	6.9
					12	4	4	78	-	112	36	67	0	4.2
9	139		3.7	58.4	13	3	4	104	25	92	1	17	38	7.9
10	113		2.6	56.8	2	6	12	118	6	92	0.5	22	41	56.7
26	71		11.9	52.6	4	6	9	107	6	78	0.5	1	42	51.2

Source: Cram et al. (1944).

Table 2.19. Viability of *Ascaris* Eggs after Digestion and Drying of Sludge Under Various Conditions

Temperature of digestion (°F)	Length of digestion (days)	Type of drying	Viability of *Ascaris* eggs	Number of drying days	Moisture content of sludge (%)
68	139	At room temp.	+	29	9.9 at 19 days
			-	35	less than 5
	108[a]	Outside	+	36	
			-	42	
	133	Greenhouse	+	78	6.9
			-	78	4.2
86	41 to 95	Greenhouse	+	18 to 81	5.8 to 11.5
			-	79	3.3
		Outside	+	42 to 171	58.4
			+	42	
			-	61	
			+	63	
			-	73	
Greenhouse	71	Greenhouse	+	107	
		Room temp.	+	47	27.0
			-	56	
		Outside	+	104	
Room temp.	113 to 139	Greenhouse	+	104	7.9
			+	118	56.7
		Outside	+	37	

Source: Cram et al. (1944).

[a] After 65 days activated sludge treatment.

Table 2.20. Effect of Drying of Sludge on *Ascaris* Eggs

Time (days)	% moisture	Average no. of ova/100 g sludge	Average % viability of ova
0	85.6	38,000	70
14	54.8	22,800	31.1
23	17.6	24,500	42.7
48	3.7	27,000	20
51	3.1	19,300	10

Source: Bhaskaran et al. (1956).

Pedersen (1981) referred to laboratory work performed by Bond (1958) for examining dried sludge for levels of *Ascaris lumbricoides* ova. Digested sludge was distributed on drying beds for up to 21 days. The solids content of the samples examined ranged from 43.7 to 65.8%. *Ascaris* ova ranged from mean values of less than 5 to 520 ova/g dry weight, of which 10 to 50% were viable.

According to Pedersen (1981), Reimers et al. (1981) showed through actual field data that, dependent on season, *Ascaris* and *Toxocara* inactivation occurred at 5% moisture content in the autumn, 7% in the winter, 8% in the spring and 15% in the summer in the US. Partly because of this variation, the authors judged that desiccation was not the only mechanism involved in reducing parasite numbers. Temperature, oxygen content, solar radiation, and time were thought to have a great influence on the survival rates.

A unique study was conducted by Reimers et al. (1983) on the effect of various conventional sludge stabilisation treatment processes on destroying parasite eggs. The results of this investigation on Southern US domestic sewage sludges indicated that, in general, conventional treatment processes (e.g. Anaerobic or aerobic digestion) were not completely effective in destroying parasite eggs. Drying beds, however, appeared to be very effective in destroying parasites. As shown in **Table 2.21** Reimers et al. (1983) applied undigested and digested sludge to drying beds and studied their effect on some persistent parasites.

Table 2.21. Average % Reduction of Viable Parasite Eggs by Unit Processes

Process	*Ascaris*	*Toxocara*	*Trichuris trichiura*	*Trichuris vulpis*	
Drying bed (following aerobic digestion)	6	8	-	6	Number of plants
	75	96	-	77	Reduction %.
Drying bed (following anaerobic digestion)	5	4	1	5	Number of plants
	97	97	100	93	Reduction %.

Source: Reimers et al. (1983).

Reimers concluded that parasite inactivation on drying beds at ambient temperatures might be possible at varying moisture contents and temperatures. He also concluded that, with good anaerobic sludge digestion, the effectiveness of sludge drying beds to inactivate parasites is greatly enhanced.

Another investigation was by Reimers et al. (1986) in which complete destruction of *Ascaris* eggs was noted when the sludge moisture content on drying beds was as high as 20%. According to Reimers, it appears that moisture is one of several variables, along with solar radiation, temperature, time, etc., that can influence the destruction of parasites in sludge on drying beds. Therefore, during the summer season, parasites can be inactivated in sludges in the Northern US as a result of the high temperatures in the sludge due to solar radiation.

In the period between June 1992 and May 1993, the survival of nonembroynated eggs of *Ascaris suum* were studied in two sludge drying beds of two different sewage treatment plants (STP) in the Czech Republic, under different climatic and geographical conditions; Michalovce STP in the East Slovak lowland (elevation 111 m above Sea Level) and Poprad STP in the sub mountain area of the Poprad valley (elevation 695 m), as stated by Plachy and Juris (1995). After 240 days, only 5% of the eggs were viable in one bed and, in the other, after 320 days of exposure 36% of viable *Ascaris suum* eggs were still recorded. Sludge dry matter in Poprad STP increased from 2.2% to 14.2% and in Michalovce STP from 4.1% to 19.2%, at the termination of the experiment. According to the author, the correlation coefficients of exposure time, air temperature, sludge drying bed temperature at 10 cm. depth, pH, dry matter to the viability of *A. suum* eggs were calculated. The most important factors reducing the viability of parasite eggs in Poprad STP were exposure time and dry matter. Other factors showed no statistically significant influence. In Michalovce STP, in addition to exposure time and dry matter, sludge pH, drying bed temperature and air temperature statistically significantly affected the viability of eggs.

Hindiyeh (1995) studied the survival of *Ascaris suum* eggs from anaerobic pond sludge on drying beds in Jordan. Her work concluded that during the summer season, 100% inactivation of eggs has been achieved at more than 78% solids content. However during winter, the 100% inactivation of *Ascaris* eggs was unattainable. Only 94% reduction of viable eggs was noted after 60 days of sand drying.

2.6. Composting

2.6.1. Introduction

Composting is a microbial reaction of mineralisation and partial humification of organic substances which, under optimum conditions, take place within a month. The most important feature of the process is the generation of heat during the aerobic decomposition of the material. This biological thermogenesis can raise the temperature of a composting mixture to 65-75°C for several days, depending on the operation and control of the process. This level of temperature is high enough to destroy all pathogenic microorganisms. However, environmental factors influence the activities of the bacteria, fungi, and actinomycetes in this oxidation decomposition process and affect the speed and course of composting cycles. The volatility and type of raw material, moisture content, oxygen concentration, carbon:nitrogen ratio, temperature, and pH are key determinants in the process.

The presence of pathogens in wastewater sludge and the increasing application of sludge to land dictate that treatments to further reduce or eliminate pathogens from sludge should play a role in land application practice. Of all treatments, composting is one of the most recommended sludge treatment systems. At a reasonable cost, the process can reduce pathogen levels and stabilise sludge sufficiently so that it can be safely utilised for agricultural purposes, and with essentially no generation of malodours. However, if sludge is heavily contaminated with heavy metals, composting with conventional bulking agents will not decrease the heavy metals content or their availability for plant intake. It is important, therefore, at this stage of the literature review to discuss the most recent sludge characterisation under Egyptian conditions. Also, agricultural residues and cement dust quantities produced in Egypt will be discussed because they could be beneficially used as potential bulking agents and amendments in composting. Sections 2.6.1.1 to 2.6.1.3 will discuss these wastes according to the most recent studies and data available.

2.6.1.1. Sludge production & characterisation in Egypt

Environmental authorities in Egypt have always had major concern over sewage sludge reuse, focused mainly on potentially toxic elements (PTEs) concentrations. This is mainly due to the uncontrolled industrial wastewater discharges that occur into sewer systems in the Greater Cairo region, which has the majority of large industries. However, data from the most recent sludge quality monitoring programme carried out by the Cairo Wastewater Organisation and the European Investment Bank (discussed in section 2.4.2), conducted at each of the 6 WWTPs in Cairo, have shown conclusively that the concentrations of PTEs are small and similar to those found in Europe and USA, as shown in **Table 2.22**. This should not lead the environmental authorities to complacency over controlling industrial discharges to the sewer system because it is important for the maintenance and improvement of the chemical quality of sludge that efforts to implement an effective industrial effluent control system should be continued.

The potential risks from PTEs result from the long term accumulation in soil, from repeated applications of sludge, that may potentially give rise to toxic effects on crops, or to animals or man consuming such crops, if soil concentrations exceed safe levels. With the current concentrations of PTEs in Egyptian sludge, the WRC (1999) stated that it would take many decades or even centuries to reach critical concentrations and the risks are further reduced by the calcareous nature of Egyptian soil, which reduces the bioavailability of the PTEs of greatest concern. The primary concern in sludge reuse should be its hygienic quality since the high prevalence of many infections in Egypt poses a potentially direct and immediate risk to human health if sludge is not treated in a controlled and effective manner. There is also a need to ensure that WWTP and agricultural workers involved in handling sludge are protected during the production process and that suitable Quality Assurance and Quality Control arrangements, together with independent auditing of those arrangements, are in place. It has been concluded that treatment processes for sludge must be designed to eliminate the most resistant microorganisms found which, under Egyptian conditions, is *Ascaris* ova (WRC, 1999).

Table 2.22. Heavy Metals content of Sewage Sludge in Different Regions, Compared to Limit Values

Element	Typical Contents (mg/kg DS)				Limits (mg/kg DS)	
	Cairo	EC	UK	USA	EC	USEPA*
Zn	1070	1000	889	725	2500	2800
Cu	263	380	473	463	1000	1500
Ni	46	44	37	29	300	420
Cd	2.9	4	3.2	7	20	39
Pb	67	153	217	106	750	300
Cr	264	145	86	40	-	1200

Source: WRC (1999).

* Limit values adopted in the temporary Egyptian Decree 214/1997.

Table 2.23 indicates the general scale of the quantities of sewage sludge produced at the present rates of wastewater flow and treatment and those that may be generated by the year 2020, according to the most recent WRC study conducted, and from the CWO and NOPWASD.

Table 2.23. Sludge Production in Greater Cairo Estimated for Year 2000 and 2020

WWTP	Year 2000		Year 2020	
	Volume (m^3/d)	Dry solids* (tonnes/yr.)	Volume (m^3/d)	Dry solids* (tonnes/yr.)
Gabal El-Asfar	318	68985	954	206955
Berka	100	21900	150	32485
Shoubra El-Kheima	100	21900	125	27010
Abu Rawash (Zenien)	110	23725	270	58765
Helwan	85	18616	170	36865
Alexandria	212	46040	382	82960
Others	42	9122	126	27365
Total	**967**	**210288**	**2177**	**472405**

Source: WRC (1999) and CWO.

* Assumes bulk density = 0.7 t/m^3 and dry solids = 85%.

2.6.1.2. Agricultural wastes & residues in Egypt

The quantities of agricultural residues produced in Egypt during the period 1990 to 1993 are summarised in **Table 2.24**. Most of these wastes are unfortunately, burnt in the fields, causing major environmental concerns. Typical wastes include cotton stalks, rice straw and sugar cane. Some wastes, such as the sugar cane, are used as fuel at some factories and some wastes, such as the wheat, barley and straw, are used as ingredients in animal fodders. However, burning of agricultural wastes is an unacceptable disposal option and consumption of these wastes in the production of a useful by-product is highly encouraged by the authorities and farmers. In addition to the huge quantities of sewage sludge produced in Egypt, agricultural wastes could be utilised in composting facilities that would supply useful fertilisers for the large desert areas surrounding most Egyptian Governorates.

Table 2.24. Estimated Quantities of Agricultural Residues (1990 to 1993)

Type	Total Production (1000 tonnes/year)			
	1993	1992	1991	1990
Cotton stalks	1424	1353	1731	1599
Maize stalks	3753	3738	3931	3754
Sorgium	691	633	576	568
Soya beans	49	58	113	110
Sunflower stalks	79	59	-	-
Sesame stalks	73	58	61	45
Lupine stalks	8	7	7	8
Rice straw	2258	2140	1937	1826
Grind nuts	113	31	30	30
Sugar beet	136	131	168	116
Sugar cane	3168	3084	3040	2998
Vegetables	783	692	733	701
Lenin	71	73	107	76
Palm	676	-	665	607
Parks waste	1230	1224	1210	1170
Medical herbs	348	320	312	307
Wheat straw	5559	5355	5671	5004
Barley straw	237	409	254	316
Broad bean	416	595	457	482
Clover	726	687	700	741
Lintel	21	15	17	14
Total	**21819**	**20662**	**21720**	**20472**

Source: Ali et al. (1998) and El-Shimi et al. (1997).

2.6.1.3. Cement dust problem in Egypt

Cement dust by pass, or the cement kiln dust, is a hazardous by-product from the cement industries. Egypt currently has 9 large cement factories and 10 large factories are under construction and expected to start operation by the end of year 2000. The factories already operating, although they have suction hoods that are connected to silos for storing the cement dust, still have a major problem with its final disposal. Currently, the cement dust is pumped into transportation trucks and dumped in the desert. Due to the nature of the dust, it tends to be dispersed into the air and carried by wind to the surrounding areas, causing significant health hazards. This is witnessed currently in the Helwan area, where one of the oldest and largest cement factories is located. According to the Sinai Cement Factory, 70 tonnes/day of cement dust is generated at its factory. The other 8 operating factories and, in future, the new factories under development will produce significant amounts. Currently, the Egyptian Environmental Affairs Agency (EEAA) is studying the possibility of using cement dust as an amendment with sludge, as well as other bulking agents, in an attempt to produce safe and sanitised compost and to consume some of the cement dust in a beneficial way.

2.6.2. Process Description

As soon as appropriate materials are piled together, the decomposition process begins. Microbes of importance in composting include bacteria and fungi. Some workers in composting include actinomycetes as a separate group distinct from bacteria and fungi. All other groups are of minor significance. The most important distinction of microorganisms is their classification in terms of metabolic action as aerobic, anaerobic and anoxic. All macroscopic organisms, and many microscopic ones, are obligatory aerobic. Other microbes using oxidized inorganic compounds, such as NO_3, NO_2, and SO_4^{2}, are anoxic. Almost immediately, aerobic bacteria and other microorganisms utilise and decompose the organic matter (including carbon, nitrogen, protein) and oxygen, to produce less complex compounds (including carbon dioxide, water, ammonia and heat). This could be expressed in the following formula, according to Hassouneh et al. (1999) quoting Haug (1993):

$$C_{10}H_{19}O_3N + 12.5O_2 \rightarrow 10CO_2 + 8H_2O + NH_3,$$

which indicates that about 12 grams of oxygen are required to stabilise each gram of sludge solids, represented by the molecular formula $C_{10}H_{19}O_3N$.

The main point here is the evolution of heat during the reaction since aerobic reactions are exothermic and heat is a major end product. Composting essentially takes place within two ranges, namely mesophilic (< 45°C) and thermophilic (45°C to 65°C). This heat, which reaches the threshold of thermophilic metabolism in a short time (1 to 4 days), is conserved within a composting pile, causing temperature to increase as long as organic matter is available and being utilised. The increase of temperature is associated with a drastic change in the chemical and physical characteristics of composting sewage sludge. The sanitisation of sewage sludge is achieved mainly by the heat generated during the process. It is noteworthy that the temperature is not the only mechanism by which the pathogens are inactivated. In fact, as the raw sewage sludge is transformed during the mesophilic phase and the subsequent thermophilic phase, the composting mass turns into a substrate unsuitable for the growth and survival of most pathogens. As the composting proceeds, new microorganisms develop in the composting mixture and compete with the pathogens. During the thermophilic phase, the vegetative forms of some mesophilic bacteria do not disappear because they develop a thermophilic tolerance up to 60°C (Dumontel et al., 1999; Nakasaki et al., 1985). According to Dumontel et al. (1999), Strom (1985) listed 34 species of fungi, 20 actinomycetes and 12 bacteria in reviewing the literature on thermophilic microorganisms found during composting, and found one species of non-spore forming thermophilic bacterium growing at 65°C.

As the bacteria consume and deplete the organic matter and nutrients in a composting pile, the microbial activity decreases and many microorganisms begin to die or become dormant. Thus temperature levels decrease and the curing period starts. During curing, materials continue to decompose but at a much slower rate. Generally, compost is judged to be ready for use by several characteristics, most importantly its organic matter, C:N ratio, CO_2 evolution, O_2 demand and temperature levels.

2.6.3. Operating Parameters

Aerobic composting can be induced to proceed in the thermophilic range, i.e. between approximately 45 and 65°C. This is mainly achieved by providing an ample oxygen supply to the composting matter through suitable methods such as perforated underlying pipes (passive composting system), forced aeration by blowers (aerated static pile system), which facilitates aerobic microbial activity. A mass of composting mixture will then pass from ambient temperature through successive stages of mesophilic, thermophilic and again mesophilic bioactivity with related changes in type and concentration of bacteria, actinomycetes (filamentous-type bacteria), fungi, and protozoa present in the waste material or imported from the atmosphere.

Because it is a biological process, environmental factors influencing the activities of the organisms determine the speed and the course of the composting cycles. The most important operating factors are oxygen content, carbon-nitrogen ratio, moisture content, pH and particle size. Organic matter subjected to optimum conditions is more rapidly decomposed (within a few weeks) than if anaerobic conditions prevail (several months). The attractive feature of well managed thermophilic composting is the rapid self heating to temperatures ranging from 50-60°C. The process thus lends itself to rapid and effective inactivation of pathogens - including helminth eggs - in human waste.

2.6.3.1. Oxygen content

Aeration of a composting pile accomplishes several important factors:

- it supplies oxygen to the aerobic microorganisms for the decomposition process.
- it provides temperature control (to maximise microbial activities and pathogen destruction).
- it removes excess heat.
- it achieves moisture removal.
- it removes carbon dioxide, ammonia and other gaseous products of the decomposition process.

Higher temperatures are achieved under aerobic conditions than under anaerobic conditions. Excessive aeration results in cooling of the compost piles, while under-aeration results in low temperatures because of anaerobic conditions. Several investigations have experimentally measured oxygen consumption rates and indicated that the consumption rate increases with increasing temperature up to some optimum level and then declines. Maximum observed oxygen consumption rates corresponding to various materials and temperatures of operation are shown in **Table 2.25.**

Table 2.25. Oxygen Consumption during Thermophilic Composting of Different Organic Wastes

Test material	Temperature (°C)	Oxygen consumption rate (mg/h/gVs)*
Mixture of garbage and sludge	65	8
Ground-up garbage	48	13.7
Straw and grass	55	2
Dairy manure	60	4.8
Paper refuse	64	5

Source: Willson (1988).

* gVs: Grams of volatile solids.

According to the Water Pollution Control Federation (1985), Willson (1977) showed that 34 m^3/h of air per dry ton of sludge moving through a forced aeration pile developed temperatures in excess of 70°C for 15 days. An unaerated pile under the same conditions remained at temperatures below 30°C. However, theoretically speaking, Cheremisinoff (1994) mentioned that the optimum oxygen concentration in a composting mass is between 5 and 15% by volume. Increasing the oxygen concentration beyond 15% will result in a temperature decrease because of the greater air flow and its cooling effect. Although oxygen concentrations as low as 0.5% have been observed inside composting windrows without anaerobic symptoms, at least 5% oxygen is generally required for aerobic conditions.

Aerobic dissimilation releases about 20 times as much heat per unit of waste decomposed as is released by anaerobic dissimilation . In this range, more heat may be produced than is removed by aeration and other losses. The temperature rises to the level at which it restricts microbial activity. The capacity of the air to remove heat is the limiting factor; most of the heat removal is due to evaporation of water and removal of the water vapour by aeration.

Moisture removal using aeration occurs as the air moving through the compost pile becomes saturated. As air is drawn through the pile it is gradually heated by the elevated interior temperatures. This temperature increase is accompanied by an increase in specific humidity, that allows the air to increase its water holding capacity. It is this temperature and specific humidity relationship that allows successful air drying, even in regions of high relative humidity.

There are three methods commonly used to sustain the supply of oxygen and therefore maintain thermophilic temperatures: a pile is regularly turned (windrow composting), ventilation pipes are arranged underneath the pile (passive composting), or forced aeration is provided by blowers or suckers (aerated static composting). In the last two cases, the pile is usually lagged to prevent heat loss. According to Rynk (1992), experimental research has demonstrated that blowing gives better control over both temperature and moisture. This means that composting with blowing is quicker and gives a higher quality end-product than processes using vacuum induced ventilation. During winter months, to avoid condensation problems in the pipes, blowing (positive air flow) is preferred.

2.6.3.2. Carbon / Nitrogen ratio

The principal nutrients that affect composting are carbon and nitrogen. The carbon/nitrogen ratio affects the microbial activity and the rate of organic matter decomposition. Microorganisms require carbon for metabolism and growth and nitrogen for protein synthesis and cell construction. Accordingly Fang et al. (1999) stated that Zucconi et al. (1981) mentioned that the application of insufficiently stabilised compost to soil, would cause severe damage to plant growth due to nitrogen uptake by microorganisms from the plants, as well as the production of toxic metabolites.

It is desirable to maintain the C/N ratio at a level that allows for optimum microbial growth - between 26 and 31 units of carbon for every unit of nitrogen. Values greater than 31 tend to slow the process and result in low temperatures. Low C/N ratios (less than 26) generally affect the compost product rather than the process. With low C/N ratios, ammonia is released and the nitrogen content of the compost is reduced. One of the major goals of composting is to produce an economical, useable product. Therefore, it is important to have the nitrogen content as high as possible. On the other hand, low C/N ratio may enhance pathogen destruction because ammonia may be an antibacterial, antiviral agent in sludge. **Table 2.26** shows the C:N ratio of microorganisms and some organic residues.

Table 2.26. Carbon to Nitrogen Ratios of Microorganisms and Some Organic Residues

Item	C/N
Micro-organisms	9-12
Raw sewage sludge	7-12
Activated sludge	6-8
Cow manure	17-19
Organic fraction of solid urban waste	26-45
Maize residue	80-90
Straw, Wheat	120-150
Fresh sawdust	500-520

Source: De Bertoldi et al. (1983).

2.6.3.3. Moisture content

Moisture content and aeration are closely interrelated in terms of displacement of air in the interstices by water and promotion of clumping and lowering of the structural strength of the material. Optimal moisture content in composting varies and essentially depends on the physical state and size of the particles. In the case of dry materials, water is often added during composting whereas dewatered sludge cake may be 70 to 80% water and requires the addition of a drying agent. The presence in sludge of so much water can result in reduced composting temperatures and affect pathogen destruction and the decomposition of the sludge.

Moisture content exceeding 60% will reduce the free pore space, resulting in anaerobic conditions. On the contrary, moisture below 40% results in a slower composting process and usually lower temperatures, which negate one of the main objectives in sewage sludge composting, i.e., to achieve high temperature.

2.6.3.4. pH

It is generally true to say that material within a high range of pH (from 3 to 11) can be composted. However, optimum pH values are between 6 and 9. Whereas bacteria prefer a nearly neutral pH (6-7.5), fungi develop better in a fairly acid environment (5.5-8). In practice it is not very easy to change the pH level in a pile. Generally, the pH begins to drop at the initiation of the composting process. This is a consequence of the activity of acid forming bacteria which break down complex carbonaceous material to organic acid intermediates. High values of pH in the initial phases of the process in association with high temperatures can cause a loss of nitrogen through volatilisation of ammonia. However, the pH of the pile is self regulating as the process goes on.

2.6.3.5. Particle size

For rapid composting, the raw material must undergo size reduction. The primary purpose of this operation is to increase the surface area of the material. The smaller the particle size, therefore, the more susceptible it is to bacterial or fungal attack because of the greater surface area exposed (Gotaas, 1956). The speed of biological oxidation is in direct proportion to the amount of surface exposed. While theoretically it may be true that the smaller the particle size, the better is the biological degradation, in practice limits exist to the size reduction, which is a function of the structural strength of the raw material. It is essential that material be reduced in size but conserve sufficient interstices for the circulation of air.

2.6.3.6. Significance of bulking agents

Bulking materials are materials added to the sludge to condition it for composting. The purpose of bulking materials is to:

- reduce the moisture content to 50-60%.
- provide structure, texture and porosity to the mass so that air can penetrate and flow through it,
- improve the C:N ratio.

The bulking materials can also influence the physical and chemical characteristics of the final product, for example they can reduce the heavy metal content of the sludge through dilution or absorption. However, according to Hassouneh et al. (1999), composting using conventional bulking agents, does not include any stage that may remove or affect the presence of heavy metals in sludge.

The ratio of the bulking agent to sewage sludge in a composting mixture will depend on the moisture content of the sludge, its density and the physical characteristics of the bulking agent. The lower the moisture content of the sludge, the less bulking agent would be needed. Theoretically, if a filter press cake has a moisture content of 60%, no bulking material is needed. In practice, however, this may not be true. Filter press cake is very compact and needs to be broken down to achieve composting. The resulting particles may require a bulking agent for structural purposes. Furthermore, since the C:N ratio of sludge is usually low, the bulking agent adds carbon for better composting.

In some cases, the bulking agent is inorganic; it's only function is to provide structural support for the dewatered sludge, to provide free air space within the voids between particles and to increase the size of pore spaces and allow easier air movement through the mixture. This is only possible with raw sludge because of the higher volatility of raw sludge. More often, the bulking agent is organic and, when added to wet sludge, it will increase the quantity of degradable organics.

The ideal amendment has a high solids content, high volatile solids, low moisture content, and a low bulk density. Some properties of various bulking agents are shown in Table 2.27.

Table 2.27. Properties of Composting Amendments

Material	Bulk Density (Kg/m^3)	Total Solids (%)	Volatile Solids (%)
Bulk Compost	590	63	50
Rice hulls	130	74	95
Sawdust	260	62	96
Straw (ground)	224	73	80
Cotton-gin waste	249	74	69

Source: Outwater (1994).

Bennett et al. (1991) evaluated different bulking agents to determine the most cost effective material. The results of the investigation showed that:

- cedar chips were too wet and did not compost well.
- yellow pine chips were too expensive and were often wet.
- seed hulls were expensive and caused odours when used as the sole bulking agent.
- sawdust did not provide sufficient porosity.

Very few studies have been carried out to examine the effect of adding alkaline materials, such as red mud, lime, clay and cement dust, in addition to the conventional bulking agents which supply the favourable composting conditions discussed previously. The addition of such materials has been used to study the effect on the maturation process, control and availability of heavy metals. Qiao et al. (1997) carried out a laboratory experiment in incubators under controlled conditions, for composting digested sewage sludge amended with red mud (bauxite refining residue) in the proportion of 0, 10% and 20% of dry matter, as well as sawdust, in order to assess the effect on the composting process. The addition of red mud increased the thermophilic temperature from 55 to 65°C, increased the decomposition rate, raised the initial pH from 5.2 to 7.1 and slowed down the decline of pH after the thermophilic stage, as a result of the higher alkalinity, and the initial moisture content of the mixture was reduced from 64% to 59% for the 20% red mud addition.

According to Fang et al. (1999), a batch composting study was performed to evaluate the feasibility of composting sewage sludge with lime, in order to study the effect on the maturation and availability of heavy metals. Sawdust was added to sewage sludge to obtain a C/N ratio of 25 and lime at 0, 0.63, 1.0 and 1.63% (w/w dry wt.) was thoroughly mixed. The small amount of lime added provided a buffering against the decrease in pH and a suitable amount of Ca, which improved the metabolic activity during composting. Addition of lime at 0.63 to 1.63% increased the initial pH of the composting mixture effectively to 7.8 and 9.2, respectively. Sludge compost with or without lime treatment reached maturation after 63 days of composting, which indicates that addition of lime did not affect the length of maturation for sewage sludge compost. However, with regard to the availability of heavy metals, a significant reduction in water soluble Cu, Mn, and Zn contents was recorded. The concentrations of Cu, Mn and Zn were reduced by more than 45, 75 and 70% at the highest lime amendments, respectively, as compared to the control pile at the end of the composing period. It was concluded, therefore, that lime amendment was effective in reducing the heavy metal availability of sludge compost by forming less soluble carbonate salts (Fang et al., 1999).

In respect of the use of cement dust by-pass, no publications are available in the literature. However, an American company, N-Viro Energy Systems Ltd., has found a way to convert the waste (sewage sludge and cement dust) into fertiliser - by mixing three parts sludge with one part cement-kiln dust. According to the very limited and brief information published on the Company's web site, the highly alkaline dust kills off lingering microorganisms, binds up the heavy metals, and increases the potassium level, with the result being an odourless, granular powder. The process utilises cement kiln dust to pasteurise, stabilise, disinfect, deodorise, dry and granulate municipal wastewater sludge.

2.6.3.7. Temperature

The most important feature of composting from the health viewpoint is the temperature achieved for the inactivation of human pathogens in sludge. All the operating factors (moisture content, aeration rate, pH, etc.) affect the temperature distribution in a composting pile. The optimum temperature is between 45 and 55°C. However, excessively high temperatures inhibit growth of the majority of microorganisms present, thus slowing down decomposition of the organic matter. Only a few species of thermophilic sporigenous bacteria show metabolic activity above 70°C: *Bacillus stearothermophilus, Bacillus subtilis, Clostridium sp.*, and non-spore forming bacteria. For rapid composting, high temperatures for long periods must be avoided. An initial thermophilic phase may be useful in controlling pathogens. After this stage, it is preferable to reduce temperatures (to 45-55°C) to allow development of eumycetes and actinomycetes which are the main decomposers of long-chain polymers, cellulose and lignin. Using forced pressure ventilation throughout the process solves the problem of temperature control. Another important feature in controlling temperature is the use of a temperature controlling unit responding to a temperature sensor placed in the pile. However, according to De Bertoldi et al. (1983), forced pressure ventilation in conjunction with temperature feed-back control seems to be the system which provides best temperature control and ensures continuity of the decomposition process, facilitates water removal and permits a predictable composting rate. On the other hand, a cheap alternative for temperature control, moisture removal and continuous oxygen supply, would be the passive composting method (discussed in section 2.6.4.1).

2.6.4. Composting Systems for Sludge

Table 2.28 shows the different composting systems which could be used for sludge. The aim of all these systems is basically that of creating the best conditions for the process. These conditions directly influence the growth and metabolism of the microorganisms which carry out the process. In composting, the main factor that can be most influenced by technology, around which system designs are developed, is the availability of oxygen. With respect to design, the equipment for providing aeration ranges from the relatively simple to the very complex. This range leads to the generalised classification of compost technology described earlier as open (windrow, passive and static pile) and closed (mechanical, in a vessel or container).

Table 2.28. Summary of Composting Systems for Sludge

OPEN SYSTEMS

- a. Windrow
- b. Passive
- c. Static pile:
  - air suction.
  - air blowing.
  - alternating ventilation.
  - air blowing in conjunction with temperature control.

CLOSED SYSTEMS

- a. In-vessel.
- b. Vertical reactors.
- c. Horizontal reactors.

2.6.4.1. Open systems

In a windrow system, the combined sludge and bulking agent is shaped into long piles (windrows) of relatively short height (90 to 150 cm). Usually this process is restricted to digested sludge, since raw sludge requires significant quantities of oxygen for the decomposition process, which cannot be supplied by turning, and thus anaerobic conditions prevail, unpleasant odours are produced and the process fails. The windrows are turned by a front end loader or suitable mechanical equipment. The turning effect mixes the wet cake and dry compost and bulking agent, increases porosity in the windrow to maintain aerobic conditions, promotes drying of the sludge by exposure to air and sun, and ensures that all the sludge is subjected to the higher temperatures achieved at the interior of the windrow. According to Parent (1982), the material should reach at least 60% total solids and the volatile fraction should be reduced to below 50%, so as to be dry and stable enough for use as a soil conditioner. The process takes several weeks, depending on the frequency of turning the windrow and the climate. Winter climate and inconsistent turning noticeably reduce the maximum internal temperatures in the windrow, increasing the likelihood of pathogen survival. Moreover, according to Caimcross et al. (1993) regular turning of windrow piles required for oxygen supply, causes recontamination of the composting sludge

A passively aerated windrow system eliminates the need for turning the pile for supplying air to the composting materials, by supplying air through perforated and open ended pipes laid underneath the pile. **Figure 2.1** shows the configuration and dimensions of a passively aerated windrow system. Air flows into the pipes and through the pile because of the chimney effect created as the hot gases rise upward out of the windrow. Pipes are placed so that the prevailing wind would pass into the pipes, through the holes, and into the compost material. Windrows are formed as usual, by thoroughly mixing the raw materials, which are then laid on top of the perforated pipes that have been covered with straw, in order to prevent clogging of the perforations as well as to encourage even distribution of air into the pile. The piles are then covered with bulking agents or mature compost, to serve as insulation, discourage flies and help in retaining moisture, odour and ammonia. When the composting period is completed, the pipes are pulled out and the base material mixed with the compost. According to Rynk (1992), this method has been found to contain odours, conserve nitrogen effectively and, most important of all, maintain high temperature levels consistently because of the lack of turning. Moreover, the method is inexpensive, solves the problem of aeration and is relatively easy to operate.

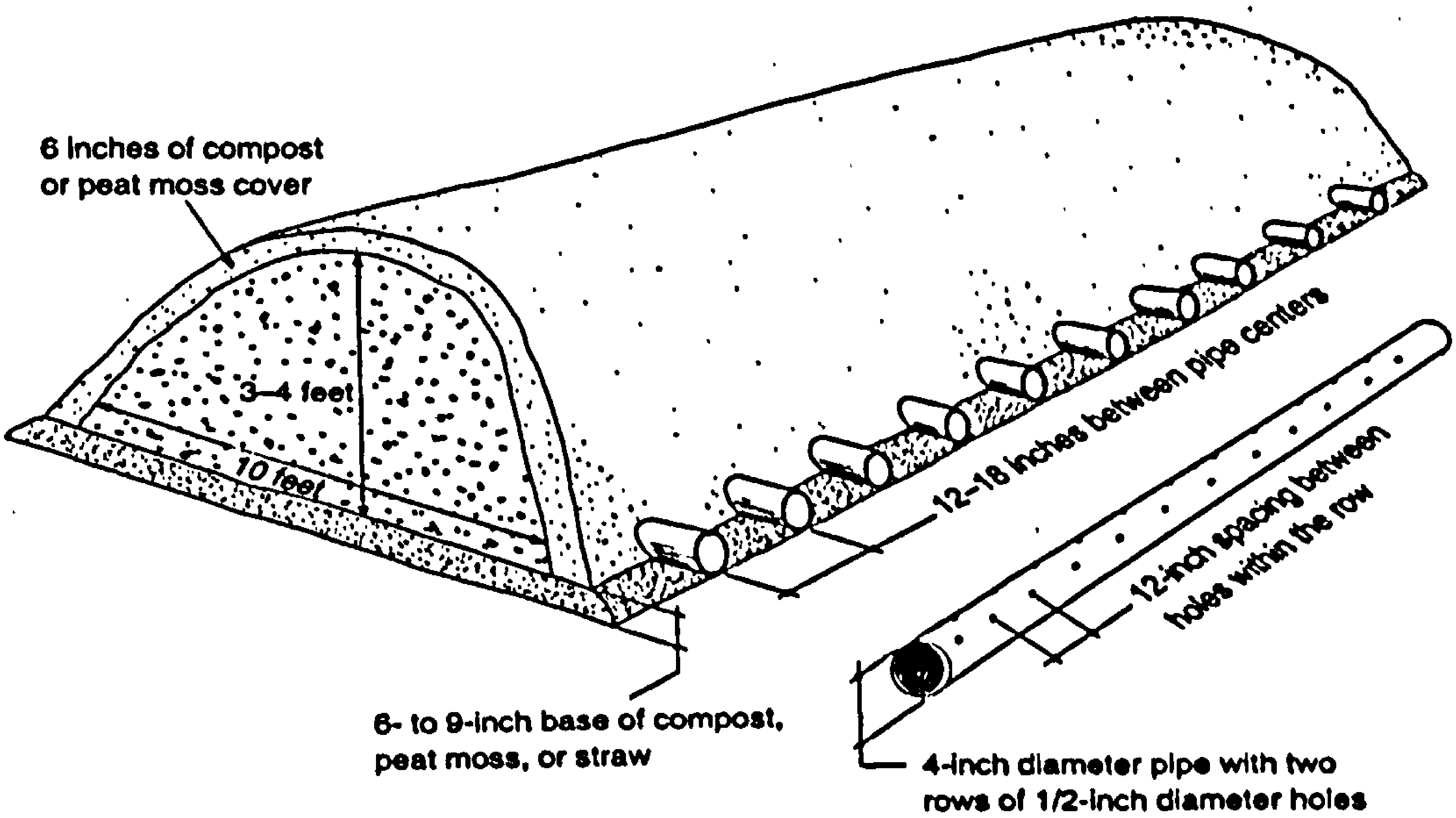

Figure 2.1. Passively aerated windrow pile

(Source: Rynk, 1992)

In aerated static pile composting, the aeration is facilitated by a series of perforated pipes running underneath each compost pile that are connected to a mechanical blower system. The pipes are covered with a layer of coarse bulking material, which acts as a manifold to provide uniform aeration and the piles are finally covered with cured compost for insulation and to provide more uniform aeration. Air is blown or drawn through the piles by industrial fans or blowers. Piles are not turned and are, therefore, "static". Blower power typically ranges between 1 and 5 hp, depending on pile size, mixture density, and piping arrangements. Forced aeration composting of sludge in aerated static piles for one month will ensure that the temperature rises to 55-60°C. Further maturation for 2-4 months at ambient temperature will produce a stable, pathogen free compost suitable for general agricultural use. This composting process is suitable for digested and raw sludge.

The aerated static pile process is comprised of four unit operations:

i. **Mixing:** Mixing involves the combination of dewatered sludge and a bulking agent by mechanical means such as a front end loader or similar type of mobile equipment. The basic criterion remains that the mixing must be as complete as possible, with thorough coating of the bulking agent but not compressed so as to restrict air movement and not to be destructive to the physical structure of the bulking agent.

ii. **Composting:** This operation includes stacking the material in piles (windrows) and aerating. The goal is to produce a pile of uniform height which encourages proper aeration and the maximisation of aerobic performance. As the pile is extended aeration pipes are laid on the ground. All the pipes are connected to a fan which is either pulling air through the pile or blowing air into the pile. Any gases drawn from the pile are eventually discharged through a stable pile of compost for odour control. Because the outer edges of the pile sometimes do not reach the required temperatures, it appears desirable to retain the option to blow air into the pile to ensure the necessary heating. The pile is aerated to supply the aerobic microorganisms with sufficient oxygen to accomplish organic stabilisation and pathogen destruction. This composting procedure lasts approximately 3 to 4 weeks.

iii. **Curing:** After active composting the resulting material is removed from the aeration system and placed in a curing pile. During curing, solids decomposition continues and temperatures initially remain elevated before falling.

iv. **Screening:** The screening operation can commence when the material reaches the desired moisture content of 40-50%. Screening involves the separation of the bulking agent from the compost with the recovery of bulking agent for later use.

2.6.4.2. Closed systems

A closed, mechanical or in-vessel composting facility is composed of a number of related components: materials, materials handling, reactors, aeration equipment, odour control facilities, exterior curing and storage facilities. A wide variety of systems are available, most having the same components, but the main difference lies in the vessel. Sludge cake, recycled compost, and bulking agents are mixed and placed in aerator reactors for composting. The reactor is a closed vessel which may be circular or rectangular, constructed of structural steel or reinforced concrete. Air is injected to control the temperature, remove the moisture, and promote biological activity. After passing through the compost, air is exhausted to the treatment system and finally dispersed into the atmosphere. When composting is complete, the material is removed from the reactor for curing and storage and, ultimately, distribution.

The in-vessel reactor has two stages: active composting and curing. The first stage is characterised by high oxygen uptake rates, high temperatures, rapid degradation of biodegradable volatile solids and a high potential for odour production. The second stage is characterised by lower temperatures, decreased oxygen uptake rates and a lower, but still significant, potential for odour production. At in-vessel facilities, the first stage is performed in a reactor and the second stage can be performed in a reactor, an exterior pile, or both.

Under the operational conditions of the closed system, uniformly high temperatures can be achieved and the composting mass is relatively unaffected by ambient temperatures and precipitation. The composting period is generally of two to three weeks duration, with temperatures reaching 70°C.

2.6.4.3. Advantages and disadvantages of composting systems

Table 2.29 provides a summary of the advantages and disadvantages of the different composting systems.

Table 2.29. Advantages and Disadvantages of Composting Processes

OPEN SYSTEMS

***a. Windrow System**

Advantages:

- Rapid drying due to moisture release when turning windrow.
- Drier product allows easier separation and high recovery of bulking agent (if practised).
- Capacity to handle high volumes of sludge.
- Good product stabilisation.
- Low capital cost if facility is not covered.

Disadvantages:

- Recontamination of piles by the regular turning.
- Large space requirements - space is needed between windrows and they cannot be piled high (> 2 m.) or wide (> 5.5 m.) due to machinery limitations and aeration requirements.
- High equipment operation and maintenance costs due to frequent turning of the piles unless a specified compost turning machine is available.
- Requires intensive monitoring of temperature (more than static pile) due to the reliance on operator skill and consistency in turning windrow piles.
- Turning piles may release localised odours.
- Inability to operate when rainfall occurs unless the piles are covered.
- Large volume of bulking agents needed to enhance aeration.

b. Passive aerated system

Advantages:

- Maintains high temperatures for longer periods of time, due to lack of turning.
- No aeration problems.
- No equipment costs required for turning.
- Very low capital costs, if facility is not covered.
- Ease in operation.
- Conservation of nitrogen.
- Capacity to handle high volumes of sludge.
- Very well sanitised and stabilised product produced.

Disadvantages:

- Large space requirements.
- Good insulation required to attain high temperature levels in outer parts of the piles.
- Relatively high loss of water, which needs to be replaced.

* Source: De Bertoldi et al (1983), WPCF (1985), Outwater (1994) and Cheremisinoff (1994).

Table 2.29. Advantages and Disadvantages of Composting Processes (continued)

***c. Aerated Static pile system**

Advantages:

- Moderate capital cost. Required capital equipment consists of perforated piping (usually plastic), concrete pads, low-pressure fans and duct work, front end loaders, a screen, temperature probes, and a condensate/leachate collection system. Roofed or enclosed structures will increase costs and may not be necessary, depending on site specific conditions.
- High pathogen destruction. Uniform aeration and pile insulation help maintain high temperatures required to kill the organisms.
- Good odour control. Pile insulation, combined with uniform aeration with blowers in the suction mode, allows odours to be treated as a point source.
- Good product stabilisation due to efficient aeration and maintenance of temperature at optimum levels.

Disadvantages:

- Requires more land than in-vessel systems.
- Rain or snow may hamper the process if uncovered and may result in a less uniform product. Cold will not affect the system, but may affect operators and equipment.
- Depending on site selection, expensive odour control equipment may be required.

CLOSED SYSTEMS

***In-vessel Systems**

Advantages:

- Low land requirements.
- Better process control than outdoor systems.
- Not affected by adverse weather conditions.
- Enclosed system allows easy addition of odour control equipment.
- Potential heat recovery can assist in maintaining optimum composting temperature.
- Reduced operating labour requirements.

Disadvantages:

- High capital cost, highly mechanised system.
- Lack of operating data for large-volume systems.
- Operation relies on specialised mechanical equipment. Possible long downtime and high maintenance costs in the case of component failure.
- High maintenance requirements, inherent with a fully mechanised system.
- The potential for incomplete product stabilisation due to short reactor detention times.
- Less operational flexibility, i.e. airflow variance, compost volume variance.
- Odours have been a problem with some systems.
- Some systems have been plagued by materials conveyance problems and lack of operating reliability.

* Source: De Bertoldi et al (1983), WPCF (1985), Outwater (1994) and Cheremisinoff (1994).

2.6.5. Benefits of Composting

Composting can offer several potential benefits in the treatment and disposal of sewage sludge. Transport costs will be reduced due to weight and volume reduction through the loss of volatile solids and moisture. The composted material is stabilised and more aesthetically acceptable, with improved handling and storage characteristics, compared with raw sludge. It is, therefore, more amenable to disposal or utilisation. Composting reduces the emission of offensive odours. Odour emissions from compost applied to agricultural land are also reduced, compared with untreated sewage sludge. In addition, pathogenic organisms are inactivated due to the elevated temperature conditions which occur during composting. Finally, the composted end-product has a market value as a soil conditioner and fertiliser for use in agriculture. **Table 2.30** summarises the differences between mature and raw compost.

Table 2.30. Differences between Mature and Raw Compost

Mature Compost	Raw Compost
Nitrogen as nitrate ion.	Nitrogen as ammonium ion.
Sulphur as sulphate ion.	Sulphur still in part as sulphide ion.
Lower oxygen demand.	Higher oxygen demand.
No danger of roots putrefaction.	Danger of roots putrefaction.
Considerable amounts of nutrients are in part available to plants.	Nutrient elements are not available.
Higher concentrations of vitamins and antibiotics.	Lower concentrations of vitamins and antibiotics.
Higher concentrations of soil bacteria, fungi, which are decomposed, easily degradable substances.	Higher concentration of bacteria and fungi, which decompose organic materials.
Mineralisation is about 50%.	High proportion of organic substances not mineralised.
Higher water retention ability.	Lower water retention ability.
Clay-humus complexes are built.	No Clay-humus complexes are built.
Compatible with plants, and may exert direct enzymatic or hormonal effects on plant roots, inducing growth promotion.	Not Compatible with plants.
Several organic molecules (e.g. polysaccharides and humic acid) improve soil texture through their effect on aggregation of clay particles.	
May suppress soilborne plant pathogens, mainly through the activity of antagonistic microorganisms.	

Source: Obeng et al. (1986) and Raviv (1998).

According to Hillel et al. (1981), the addition of sludge composts to soils is known to improve soil physical properties as evidenced by:

- increased water content.
- increased water retention.
- enhanced aggregation.
- increased soil aeration.
- increased permeability.
- increased water infiltration.
- decreased surface crusting.

One of the greatest benefits from the use of compost is to reduce the water requirements for plant growth. In arid and irrigated areas this may mean water conservation and reduced irrigation frequency.

2.6.6. Effect of Composting on Parasites

Pathogen destruction during the composting process using conventional bulking agents, may occur primarily as a result of two actions: thermo kill by temperatures above 50°C for several days and microbial competition. According to De Bertoldi et al. (1982), a variety of saprophytic microorganisms participate in the composting process; these microorganisms might be considered the indigenous or natural microflora of the compost system. Municipal sludge contains a second microbial population, the pathogens, which represent a numerically insignificant fraction of the total microbial population. Hence, competition comes into play when the community is heterogeneous and the population density is high relative to the supply of a limiting feature of the environment. The indigenous saprophytic population has a distinct competitive advantage over the other population; composting material is not the natural environment for pathogenic microorganisms, therefore in this ecosystem competition will tend to result in the elimination of the less fit rival.

2.6.6.1. Open systems

Some researchers agree that the destruction of parasites (including *Ascaris*) by non-turning composting methods, such as the aerated static method, is much faster and more effective than windrow composting. According to Cairncross et al. (1993), turning of the piles tends to reduce the degree of pathogen removal, due to the recontamination of the internal portions of the pile that have already reached high temperatures, enough to kill the pathogens. Accordingly, processes that eliminate the need for turning for aeration are likely to be much more effective. Moreover, the windrow system is now considered to be a primitive operation, which is very difficult to control and produces a variable quality end product. Cairncross et al. (1993) recommended forced aeration composting methods that are capable of inactivating *Ascaris* in one month.

According to Shuval et al. (1981), Scharff (1940) used windrow composting for sewage sludge mixed with village refuse in a Singapore village, and realised that two months after the commencement of composting, the heap had reduced to almost 1/3 its original size. The compost is then fully matured and, according to Scharff, can be used on the land. The temperatures reached in the first week averaged 65°C and this level was maintained (average 65°C) during the first three weeks. Scharff reports that, by the end of the third week, the compost, was free of viable intestinal worm eggs.

Shuval et al. (1981) mentioned that Stone (1949) recorded high temperatures of digestion between 60 to 65°C in the first days and 49°C or less in the next 15 days in the windrow composting facility at using rice straw, ashes and garbage as bulking agents with sewage sludge, the product was practically free from pathogenic organisms and *Ascaris* eggs.

Strauss (1985) stated that Scott (1952) performed proper thermophilic windrow composting of a mixture of fresh nightsoil, dry vegetable matter (straw), ashes and soil in China. Total inactivation of *Ascaris* eggs was achieved after the fourth turn (35 days elapsed). The process worked smoothly even though ambient temperatures reached as low as 15°C.

Scott (1952) also referred to composting of 1:1 mixtures of nightsoil and municipal refuse in several cities in India, where 3-4 months was required for total inactivation of *Ascaris* eggs.

According to Kalbermatten et al. (1982), Wiley and Westerberg (1969) seeded primary sewage sludge with the ova of *Ascaris lumbricoides*. The sludge was composted in a forced aeration pile and sludge temperature varied from 60 to 70°C. All samples taken were negative for viable ova after 4 h. The authors concluded that a temperature ranging from 60 to 70°C maintained for 3 days would destroy all pathogens.

According to Shuval et al. (1981), Smith and Selena (1976) reported for a Los Angeles sludge composting operation with windrows, that temperatures between 55 and 60°C were achieved, resulting in negative findings for parasite ova.

According to Feachem et al. (1983), the temperature/time profiles to be reached during composting, to assure a satisfactorily sanitized product, were set as 1 hour at >62°C, 1 day at >50°C, or 1 week at >46°C. **Figure 2.2** shows the safety zone area. Any treatment providing appropriate time and temperature combinations shown in Figure 2.2 will assure the destruction and inactivation of all excreted pathogens.

The variation in internal temperature of compost is a major problem. According to Strauss (1985), Nell et al. (1983) conducted pathogen survival tests in pilot scale composters and full-scale composting plants, composting sewage sludge and refuse or wood chips at mass ratios of 1:2 to 1:7. In pilot tests, where maximum temperatures of 60°C to 70°C were reached after at most one week, all *Ascaris lumbricoides* eggs were inactivated, at the latest after 8 days. In one pilot run, the maximum temperature attained was only 39°C, resulting in essentially zero reduction of *Ascaris* eggs within the first ten days. In full scale composting with temperatures rising to 72°C, 8 weeks were required for total inactivation of *Ascaris* eggs.

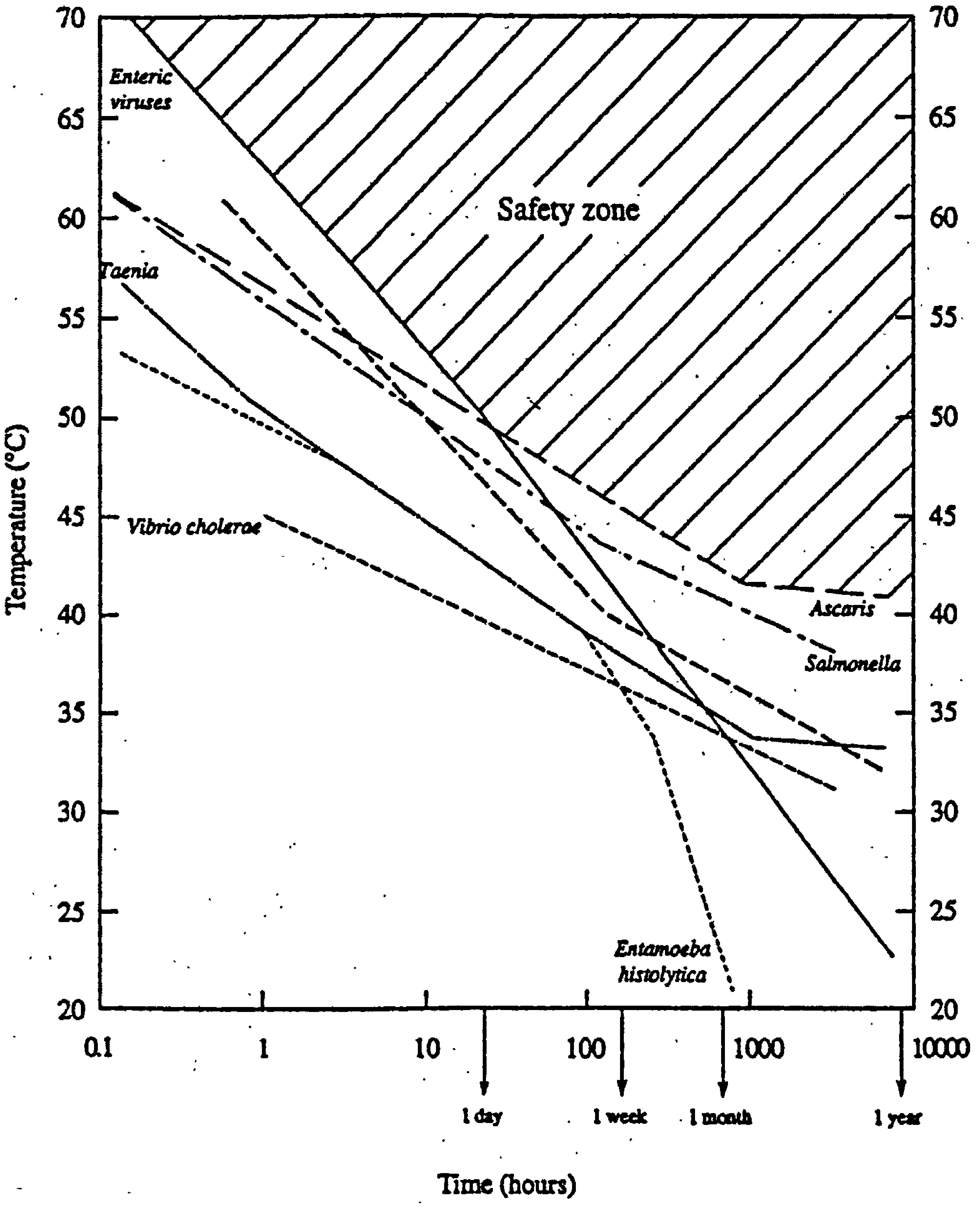

Figure 2.2. Effect of Time/Temperature Relationship on Pathogens Reduction in Sewage Sludge

(Source: Feachem et al., 1983)

Havelaar (1984) concluded that the efficiency of windrow composting in parasite egg destruction ranges from poor to good, depending on the climate and the homogeneity and frequency of turning.

Table 2.31 indicates the efficiency of windrow composting under ideal and real situations, according to Strauss(1985).

Table 2.31. Survival of Pathogens during Treatment (ideal and real situation)

Treatment system	Operation	Survival of Helminths
Ideal: Thermophilic composting	T= 50-70°C, t ≥ 1 day T= 40-45, t ≥ 1 week For all parts of pile	-
Real: Thermophilic composting	T ≤ 40-50°C; t ≤ 1 month; not All parts of pile subjected to sufficiently high temperatures	0

Source: Strauss (1985).
-: zero survival.
0: Survival in low concentrations.

Search of the literature has revealed little data on the effect of aerated static pile systems on parasite destruction. However, some data supported the high efficiency of that system due to the controlled operational parameters (see section 2.6.4.1). An impressive study funded by the USEPA, according to Goldstein et al. (1988), analysed 498 samples of composts from 26 locations. Composts from two facilities (a windrow operation and an aerated static pile operation) were sampled weekly for one year and analysed for the presence of pathogens.

Five compost products were sampled weekly at the windrow facility. They included the final compost produced and four commercially marketed compost-based soil amendment products. The two weekly sampling points at the static pile facility were the final screened compost that was utilised in a number of bulk distribution programs and the unscreened compost. Review of the data gathered in this investigation was very encouraging for compost facilities. Most classes of pathogens were not detected in most of the 354 sludge compost samples taken from the two facilities tested each week.

EPA personnel concluded that:

- No health hazard was found with respect to parasitic helminth ova. In fact, no viable helminth ova were detected in any sample.
- The researchers found no reports of anyone ever getting sick from using a sludge compost-based fertiliser or soil amendment product.

- The project author found a correlation between the amount of attention paid to the windrow composting process by the operators and the quality (microbiologically) of the final compost product. This reinforces the need for good operator training and operational manuals.

Dumontel et al. (1999) stated that Golueke (1983) estimated that a residence time of 3 days at 55°C should be sufficient to assure sludge sanitisation and such a temperature/time profile is the most widely used in composting plants. Coppola et al. (1983) found good sanitisation in a compost that was at temperatures >50°C for 9 days. Dumontel et al. (1999) mentioned that Pereira Neto et al. (1986) also reported that maintenance of temperature between 55 and 60°C for 3 consecutive days allows the inactivation of pathogens.

2.6.6.2. Closed systems

Strauch (1982) performed experimental work with *Ascaris* eggs in different bioreactor systems (BAV and Kneer). As shown in **Table 2.32**, *Ascaris* eggs survived on two occasions when too low temperatures, caused by disturbances in aeration, occurred during the course of the experiment.

In conclusion, it can be said that, both types of reactors can produce a disinfected product. Due to the fact that technical disturbances seem to occur relatively frequent by, special supervision of the temperature zones in the reactor is necessary, for hygienic reasons.

Havelaar (1984) also concluded that bioreactors give good parasite destruction due to the high temperatures attained (50-80°C). However, due to fluctuations in aeration in relation to increase in compost quantity, a significant decrease in temperature can be experienced. Accordingly, he recommended continuous supervision of temperature and aeration rate.

Table 2.32. Results of Composting Experiments with *Ascaris* Eggs in a Bioreactor

Experiment no.	No. of samples	Retention time (hr.)	Temperature (°C)	Detected samples
1. (BAV system)	10	24	67	-
	10	48	70	-
	10	72	72	-
2. (BAV system)	10	24	55	+
	10	48	50	+
	10	72	45	+
3. (BAV system)	10	24	72	-
	10	48	80	-
	10	72	80	-
4. (BAV system)	3	24	55	-
	3	48	50	-
	3	72	50	-
5. (Kneer system)	15	24	75	-
	15	48	70	-
	15	72	69	-
6. (Kneer system)	15	24	50	(3)
	15	48	53	(3)
	15	72	49	(3)
7. (Kneer system)	15	24	66	-
	15	48	67	-
	15	72	65	-

Source: Strauch (1982).
Material: Sludge compost saw dust.
(Number)- Number of detected samples.

2.7. Summary and Conclusions

The natural treatment mechanism and long retention time in wastewater stabilisation ponds allow a high degree of digestion and stability of the accumulated sludge. This has been proved through the physicochemical analyses made by several researchers (Sarkar, 1972; Ghosh et al., 1982; and Carre et al., 1987). Regarding the fertiliser value of anaerobic pond sludge, researchers have agreed that N, P and K values are relatively low compared with commercial inorganic fertilisers. However, according to Hindiyeh (1995) and Ghosh et al. (1982), the upper sludge layers which are the recently deposited sludge and therefore less digested showed a significant increase in values of N, P and K. Very little information has been found regarding the fate of parasites in anaerobic ponds' sludge (Silva, 1982; Saqqar & Pescod, 1992; and Hindiyeh, 1995), which is surprising, considering that this issue is most crucial and governs the applicability of applying sludge to agricultural land, with or without further treatment.

Some parasites which are commonly found in sewage sludges are pathogenic to man and animals, the eggs of some remain viable for long periods and they are capable of surviving most of the conventional procedures used to process sludge, except those involving heat. For these reasons, the land application of infected sludges is a cause of concern. From the reviewed literature on the persistence of parasites, it has been concluded that *Ascaris* ova are the most resistant to treatment and the absence of them from sewage sludge would therefore indicate that the sludge was free from parasitic ova. This is basically due to the resistant structure of the ova, which prevents penetration of all sorts of materials for a variable period of time. According to Steer et al. (1974), Hannan (1981), Hillel et al. (1981), Feachem et al. (1983), Reimers et al. (1986) and Smith (1996), *Ascaris* ova have been considered as the standard by which the safety of sludge disinfection measures and agricultural applications can be assessed.

The Egyptian sludge regulations have been issued following analyses of the data obtained in the Cairo Sludge Disposal Study. Environmental authorities in Egypt have always had major concerns over sewage sludge reuse, previously focusing on the concentrations of potentially toxic elements (PTE). However, the field and research data from the most recent sludge quality monitoring programme have shown conclusively that the concentrations of PTEs in Egyptian sewage sludges are quite small and similar to the levels found in European sewage sludges. The primary concern in sludge reuse should be its hygienic quality and, under Egyptian conditions, treatment processes for sludge must be designed to eliminate the most resistant microorganisms found in Egypt, which is *Ascaris* (WRC, 1999).

The success of the sludge drying bed operation depends on a large number of variables. Obviously, climatic and atmospheric conditions (such as temperature, sunshine intensity, humidity, rainfall, air velocities, and alternate freezing and thawing) play an important role and are only imperfectly controlled, even when glass enclosures are provided. Certainly, the depth of sludge application, the drainage media and the nature and moisture content of the sludge influence the bed performance. According to Reimers et al. (1983), with good prior sludge digestion (especially anaerobic) the effectiveness of sludge drying beds to inactivate parasites is greatly enhanced. Moreover, most authors have concluded that time, temperature, exposure to sunlight and desiccation are the principal lethal factors acting on parasites. However, holding times tend to be less in warm climates than in temperate regions, and thus drying beds are definitely a process recommended for hot countries and considered most suitable (Pescod, 1971). Data discussed in this chapter covered nearly all operating parameters affecting parasites inactivation on drying beds. It is clear that parasite removal efficiency is very high under very low moisture content and desiccation conditions (< 5%), which is not practicable. Comparing the efficiency of drying beds in inactivating parasites under different conditions proves that the use of drying beds for this purpose would be limited to hot countries with plenty of sunshine.

The different composting systems available are able to produce a hygienically safe product provided that the operating parameters (temperature, pH, moisture content, etc.) are within the appropriate limits. However, temperature and aerobic conditions are very critical composting parameters. Small variations in temperature and the availability of oxygen can affect microbial activity and biomass in composting sewage sludge much more dramatically than small changes in other operating parameters. According to numerous researchers, static aerated piles (forced or non-turning piles) have proved to be much more efficient and reliable in inactivating parasites, compared to the windrow composting system (turning is essential for supply of oxygen). The literature survey proved that windrow composting is unreliable for inactivating parasites and that, according to Cairncross et al. (1993), turning of piles causes recontamination of the composting sludge. On the other hand, a passive composting system can solve the high costs and operating problems incurred with the aerated pile system, yet still maintain the non turning of piles and produce a compost free of parasites. Surprisingly, no studies have been published regarding the effect on parasites of composting using the passive technique. Moreover, over the last few years, little research has been carried out to study the effects of adding various amendments such as red mud, lime and clay, with the sludge-bulking agent mixture, in terms of the maturation process, its control and the availability of heavy metals. No research has been carried out to assess the effects of such amendments on the inactivation of parasites.

From the literature reviewed, the following conclusions have been derived:

- Under Egyptian conditions, parasites and especially *Ascaris* ova are the primary health hazard associated with land application of sewage sludge, and not PTEs as was believed for a long time.
- Few data on parasite survival in wastewater stabilisation pond sludges are available.
- Few data are available on sand bed drying of anaerobic pond sludge and its effect on the survival of *Ascaris* ova.
- No data are available on the effect of passive composting of sewage sludge, in respect of the maturation process (final compost quality) and the survival of *Ascaris* ova.
- No data are available on the effect of adding cement kiln dust and other waste amendments to the compost mix, in respect of the stabilisation process and the survival of *Ascaris* ova.

Under Egyptian conditions, all the above-mentioned topics have not been studied and research work on such cost effective and simple technology methods for sludge dewatering and treatment would be very helpful for a developing country.

CHAPTER THREE: EXPERIMENTAL INVESTIGATIONS METHODS OF ANALYSIS

3.1. Physical & Chemical Analysis

3.1.1. Hydrogen Ion Concentration

pH values of the compost and sludge samples were measured directly in the laboratory using a glass electrode pH meter.

3.1.2. Temperature

Sludge sample and ambient air temperatures were recorded directly in the field using a mercury thermometer with operating range from 0 to +100°C. Temperatures within the compost piles were recorded directly in the field using an 80 cm temperature probe, with operating range from -200 to 1370°C, manufactured by Hanna Instruments, USA (model no. HI93530).

3.1.3. Density

The density of samples was analysed according to Standard Methods (APHA, 1992).

3.1.4. Moisture Content

Moisture content was analysed according to Standard Methods (APHA, 1992).

3.1.5. Total Dry Solids

Total dry solids were analysed according to Standard Methods (APHA, 1992).

3.1.6. Carbon Dioxide

The evolution of carbon dioxide (as a percentage) in the air voids within the compost piles was measured directly in the field using an apparatus manufactured by SandBerger, Austria. First, the apparatus had to be calibrated, which was achieved by opening the vessel's valve to the ambient air and adjusting the indication meter on the side of the vessel to 0 %. The vessel, containing 33% potassium hydroxide solution for CO_2 absorption, was then attached to a hand suction pump, which was connected to an 80 cm probe perforated to allow sucked air to pass through. The probe was then inserted into the compost pile and, once the air sample had been sucked from the pile, the air suction pump was taken off the vessel. The vessel was then turned upside down, to allow the CO_2 gas to be absorbed completely in the solution. It was then inverted again and the reading of the CO_2 percentage was taken immediately from the indication meter on the side of the vessel. However, after the solution in the vessel had been used for a certain period of time, it required to be replaced.

3.1.7. Nitrogen Forms

Total, nitrate and ammoniacal nitrogen were determined according to Jackson (1973).

3.1.8. Organic Carbon and Organic Matter

The organic carbon content was determined by the rapid titration method of Wilkley and Black, according to Black et al. (1965). The value of the organic carbon was used to calculate the organic matter, using the following relationship:

$$OC = OM/1.7241$$

3.1.9. Phosphorus

Total phosphorus was determined according to Standard Methods (APHA, 1992).

3.1.10. Potassium

Potassium was determined according to Standard Methods (APHA, 1992).

3.1.11. Heavy Metals

Heavy metals analysed included iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr) and mercury (Hg). All samples were analysed using an Atomic Absorption Spectrometer in accordance with Standard Methods procedures (APHA, 1992).

3.2. Parasitological Analysis

Materials used for the parasitological analysis were the following:

- Flotation solutions (zinc sulphate, magnesium sulphate). The solutions were made up at 33.3% to ensure a specific gravity of 1.18.
- Detergent, commercial Clorox (Sodium hypochlorite 6%)
- 0.1N Sulphuric acid. The solution was made up by adding 2.8 ml of sulphuric acid solution to 1000 ml of distilled water.
- Glassware (centrifuge tubes 10, 20, 30 & 50 ml, petri dishes, microscopic slides, conical flasks).
- Gauze.

3.2.1. Identification Technique

The technique of Meyer et al. (1978) was adopted in this research for use in the identification of *Ascaris* eggs in the sludge, dried sludge and compost samples. The percentage recovery of the *Ascaris* eggs using this technique is unknown. The sample size collected from the sludge, dried sludge or a compost pile was approximately one half a litre. As a precaution the detection procedure was repeated three times for the negative samples, to give a more reliable indication of the presence or absence of *Ascaris* eggs.

1. Two heaped tea spoons (5 ml.) of sludge or compost were placed in a glass beaker. A solution of water and detergent (6.0% Chlorox solution), with mixing ratio 1:1, was added.
2. The sludge or compost/detergent mixture was thoroughly mixed and comminuted.
3. After thorough stirring and soaking for 30 minutes to loosen the adherent eggs, the sludge slurry was filtered through gauze, to remove coarse particulate matter.
4. The sieved suspension was allowed to stand undisturbed in a large conical flask for two hours; *Ascaris* eggs, together with fine sludge particles, settled to the bottom of the flask.
5. The supernatant from the conical flask was discarded leaving the sediment.

6. The flotation solution (33% zinc sulphate, specific gravity 1.18 or magnesium sulphate solution) was added to the sediment layer and shaken well. The sediment was suspended in the flotation solution.
7. The mixture was placed in a wide diameter centrifuge tube and spun for 2 minutes at 2000 rpm.
8. The top layer of flotation fluid from each centrifuge tube was removed with a clean plastic syringe, the fluid injected onto a glass microscope slide and covered with a cover slip to prevent drying before starting the microscopic examination. Alternatively, the sediment with the flotation solution was poured into a wide tube, covered with a glass microscopic slide and left for 10 minutes before examining directly.

3.2.2. Viability Examination of Positive Samples

The technique that was used for assessing the viability of *Ascaris* eggs was the incubation technique as described by Meyer et al. (1978). The technique is convenient and relatively simple; however, the main disadvantage is that it takes several weeks to get a final result.

For all positive samples from the dried sludge and compost, viability examination had to be performed to prove the non-infectivity to humans, due to the fact that complete disintegration of *Ascaris* eggs takes time. The identification technique was repeated up to the flotation procedure and then the following procedure was followed:

1. The surface film was pipetted, diluted with water and centrifuged for 2 minutes at 2000 rpm.
2. The supernatant was discarded and the sediment placed in a petri dish, filled with a solution of 0.1N H_2SO_4 and lined with wet gauze, and covered to maintain humidity.
3. Petri dishes were placed in an incubator at 30°C ± 1°C for 30 days. Samples were examined every week to check their ability to develop.
4. The precaution was always taken that the slides were not allowed to dry, accordingly wetting of the gauze was carried out several times.

EXPERIMENTAL PROGRAM I: DRYING BEDS

3.3. Introduction

The major purpose of this study was to evaluate the efficiency of another simple, low technology and a cheap sludge treatment process, namely drying beds, on the fate of *Ascaris* eggs. This study was carried out on sludge from the waste stabilisation pond treatment plant located in Mit Mazah village, Daqahlia governorate, Egypt. Sludge accumulated in the primary anaerobic pond has been under investigation, in regard to the sludge distribution, volume and characterisation, after which sludge has been used in the field on pilot scale drying beds. Studies were carried out during the winter and summer periods, in order to study the effect of weather conditions on the process, sludge and *Ascaris* eggs. Also, different depths of sludges were applied on the drying beds with different drainage medium configurations. This was mainly to study the changes in total solids content and viability of *Ascaris* eggs.

3.4. Treatment Plant Description & Sampling Locations

3.4.1. Mit Mazah Waste Stabilisation Pond

Mit Mazah waste stabilisation pond system (WSP) was designed to serve Mit Mazah village for a maximum population of 8,500 with a design flow of 625 m^3/day. The plant started to operate at the end of 1991 and performed satisfactorily, even though the influent was about twice the design flow (1300 m^3/day).

The raw wastewater from the village is collected in a sump and pumped intermittently through a 200 mm steel pipe to the treatment plant. Prior to entering the stabilisation ponds, the wastewater is screened to get rid of large objects and this is followed by a flow measuring weir. The plant consists of three ponds in series, an anaerobic pond followed by an aerated facultative pond and, finally, a maturation pond. The general layout of the pond system is shown in **Figure 3.1.** Due to the limited land availability, all possible savings in order to reduce the area requirement were taken into consideration in the design of the Mit Mazah plant. Primarily, an aerated pond replaced a low cost facultative pond and, secondly, the walls of the anaerobic and aerated ponds were constructed from reinforced concrete, rather than being earth embankments. **Table 3.1** summarises the pond sizes and design parameters for the Mit Mazah sewage treatment plant.

Table 3.1. Pond Sizes & Design Criteria for the Mit Mazah Treatment Plant

Pond type	Total depth (m)	Water depth (m)	Area (m^2)	Volume (m^3)	Retention time* (days)	BOD_5 removal (%)
Anaerobic	4.5	4.0	647	1138	5.0	56
Aerated	4.5	4.0	315	1260	2.52	80
Maturation	2.0	1.5	1670	2500	4.23	80
Total	-	-	**2632**	**6348**	**12.69**	**95**

Source: WHO (1992).

* Based on flow of 625 m^3/day.

3.4.2. Anaerobic Pond Sludge

3.4.2.1. Sampling for sludge distribution & volume

Since the start-up of the Mit Mazah plant in 1991, sludge had not been emptied from the anaerobic pond. Accordingly, at the time of this study the depth of the sludge layer was expected to exceed the limit expected in setting the design criteria and have an adverse effect on the plant performance and thus the final effluent quality. However, regarding the sludge quality, it was expected that it would be well digested due to the prolonged anaerobic decomposition process it had been undergoing.

During the initial phase of this research (July, 1997), the sludge layer thickness was measured all over the anaerobic pond for the determination of sludge distribution and thus the volume. A sludge depth sensor device (Sludge blanket detector. PHOX systems Ltd, UK) was used, which is composed of a metal detector that works by signalling zero light transmissivity as the metal detector touches the sludge layer. This metal detector was suspended from a graduated wire and, as soon as the metal detector reached the top sludge layer, a beep signal was given. Measurements were taken along the sidewalls and along the centreline of the pond, at about 5 metres intervals. The same excavator used for transporting the anaerobic pond sludge to the drying beds (Figure 3.4) was used for taking measurements at the middle of the pond, with someone sitting inside the bucket holding the sludge depth sensor device.

3.4.2.2. Sampling procedure for wastewater & sludge characterisation

It was important to analyse the influent wastewater, which would give an indication of the organic loading and nature of the wastewater and thus the accumulated sludge quality. Accordingly, one litre samples were collected every day for three successive days from the sump. Samples were stored in a refrigerator after collection, and after thorough mixing, a representative composite sample was analysed for physicochemical characteristics and *Ascaris* content.

Regarding sludge, five samples were taken from different locations in the anaerobic pond. As shown in Figure 4.1 (Chapter 4), two samples were taken from the inlet side, two samples from the outlet side and one sample from the middle of the pond. The conventional clam style grab sampler was used initially, which is a simple device that is suspended by a rope and once it hits the sludge layer and is pulled up, its jaws close on the sludge deposit. However, due to the ageing of the sludge, the layer was very hard to penetrate and required force to drive the sampler into the sludge layer. Accordingly, samples were collected using the New Gilson Corer sampler (Duncan & Associates, UK). This device consists of a corer tube pole extendable to 4 metres length. At the end of the pole, a 450 mm tube with a cutter at the end is attached. Once the pole is driven vertically downwards to the desired depth and pulled out, the cutter closes on the sediment.

The two samples at the inlet side were very well mixed and a representative composite sample was analysed. The same procedure was followed for the outlet side samples, with one representative composite sample being analysed.

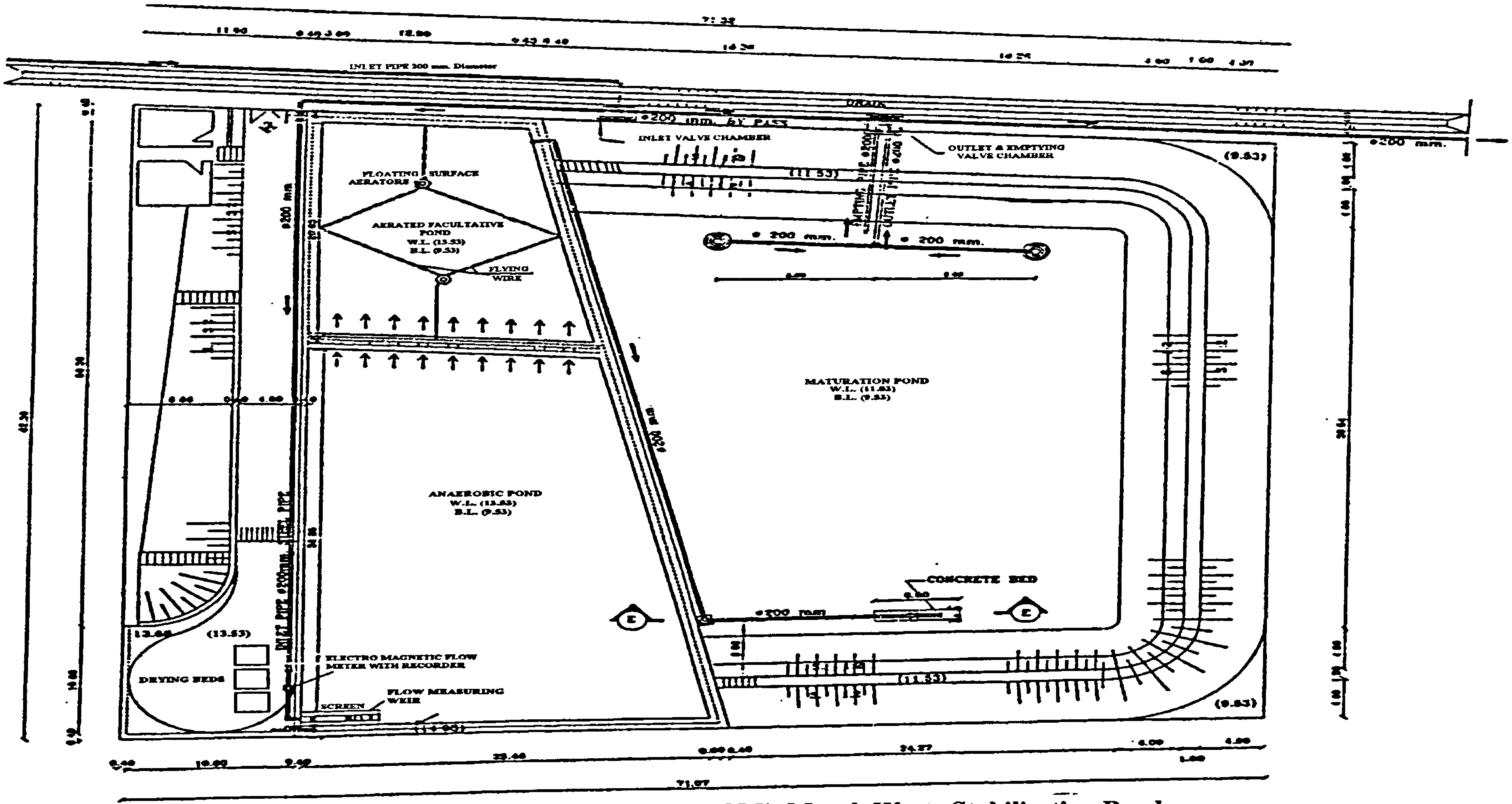

Figure 3.1. General Layout of Mit Mazah Waste Stabilisation Pond

3.5. Materials & Methods

3.5.1. Materials

3.5.1.1. Anaerobic pond sludge

Anaerobic pond sludge from Mit Mazah waste stabilisation pond, Daqahlia governorate was applied to the drying beds. The physicochemical composition and *Ascaris* content of the anaerobic pond sludge is presented in Chapter 4 (Table 4.2), and Section 4.1.1.2.

3.5.1.2. *Ascaris vitilorum* eggs

Fresh cattle ascarid was obtained from the intestines of infected cattle from a slaughterhouse. The female worms, which have both ends tapered (male worms have their posterior end coiled), were identified and collected in petri dishes. Female worms have been opened and the uterus has been extracted from the worm's body. The uterus was squeezed to remove *Ascaris vitilorum* eggs. Extracted eggs were placed in formal saline solution (1% formaline, 99% saline), as a medium for culturing the eggs as well as preventing putrefaction, which does not affect their survival.

3.5.2. Experimental Procedures

3.5.2.1. Application of anaerobic pond sludge on drying beds

The objective of this study was to evaluate the effectiveness of anaerobic pond sludge storage in natural drying beds as a method for inactivating *Ascaris* eggs. This would be achieved by studying the survival of eggs at different sludge depth applications on drying beds during winter and summer periods. An additional objective was to assess the changes in sludge characteristics (solids content), which could be related to *Ascaris* inactivation. These two objectives would finally evaluate the suitability of the sludge for land application as fertiliser.

a. Design of air drying beds

Three pilot-scale drying beds were constructed at Mit Mazah WSP, adjacent to the anaerobic pond, as shown in Figure 3.1. **Table 3.2** summarises the details of the drying beds design used in this study. Sludge dewatered through perforated under-drainage pipes that were adequately supported and laid at a slope of 2% to ease the flow of filtrate. These pipes were covered with a layer of coarse gravel (> 4 cm), two layers of different diameter size fine gravel (3 mm and 6 mm) and a fine sand layer. The sand media characteristics were clean, no clay or organic matter, with effective size of 0.3 to 1.2 mm. **Figures 3.2 & 3.3** shows the cross section of the drying beds adopted in this study during the winter and summer seasons, respectively, with the configuration, grading and depth of the drainage medium. During the winter season, two sludge applications were performed, each with different sludge and sand depth layers. However, during the summer season, only one sludge application was performed with different sludge layers, but the same sand layer depth. **Table 3.3** summarises the sludge applications during the winter and summer trials.

Table 3.2. Details of the Pilot Scale Drying Beds at Mit Mazah Site

Parameter	Description
Number of beds	3
Construction of beds	• Brick walls • Concrete flooring
Underdrains	• Perforated plastic pipes laid with open joints • 10 cm diameter • 2% slope
Dimension of beds	L * W * D (m) = 3 * 3 * 1.1
Sludge layer depth	15 – 25 cm
Sand layer	• Depth: 10 – 30 cm • Size: 0.3 - 1.2 mm
Fine gravel layer	• Depth: 10 cm • Size: 3 – 19 mm
Coarse gravel layer	• Depth: 20 cm • Size: >4 cm

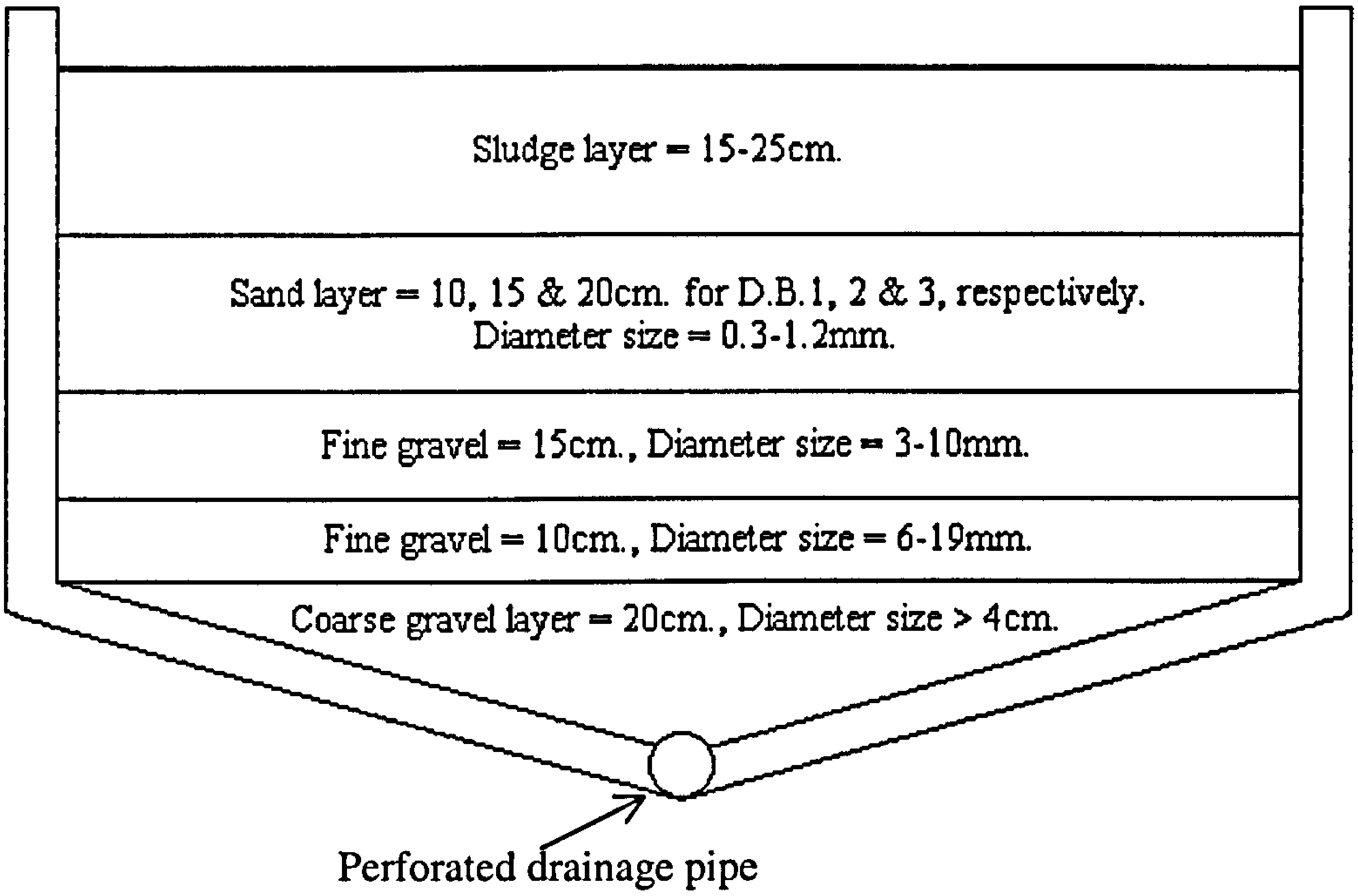

Figure 3.2. Cross Section through Drying Beds used during Winter Trials

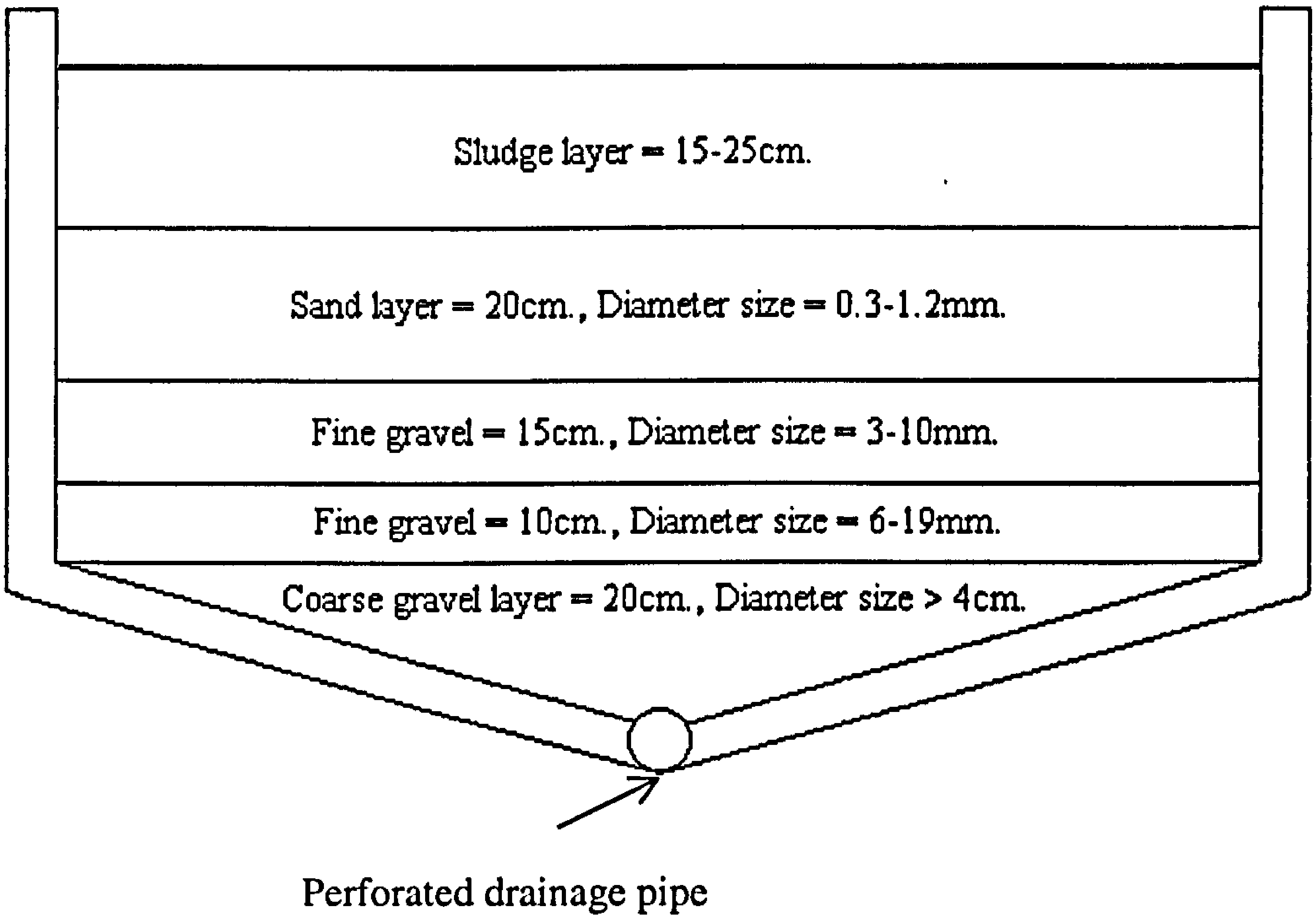

Figure 3.3. Cross Section through Drying Beds used during Summer Trial

Table 3.3. Sludge and Sand depths for the Drying Beds during the Winter and Summer Seasons

Month (unit)	Layer	Thickness (cm.)		
Winter Season		**Drying Bed 1**	**Drying Bed 2**	**Drying Bed 3**
First Trial	**Sand**	10	15	20
	Sludge	25	20	15
Second Trial	**Sand**	10	15	20
	Sludge	15	25	25
Summer Season	**Sand**	20	20	20
	Sludge	15	20	25

b. Sampling points and frequency

Sludge from the anaerobic pond at Mit Mazah WSP was transported to the drying beds using an excavator, from approximately half way along one side, as shown in **Figure 3.4.** The sludge was well distributed on the drying beds at different depths. For the winter and summer periods, the drying time was 2 months each. Grab samples of the sludge were collected from the drying beds at days 1, 7, 18, 32 and after two months for the first trial during the winter season. In the second trial during the winter season, samples were collected at days 1, 7, 18, 41 and after 2 months. During the summer trial, samples were collected at days 1, 3, 6, 17, 34 and after two months. It is important to mention that from each drying bed, one sample was collected and this sample was assumed to be representative of the entire bed.

c. Parameters measured

Weather conditions affect the performance of the drying beds and, accordingly, during the drying period the ambient air temperature (°C) was recorded at 10 a.m. and 2 p.m., throughout the drying period. In addition, the sunshine (hours) and rainfall rate (mm/month) were obtained from the national weather station in Cairo.

During the drying period, sludge temperature was measured every day, at 10 a.m. and 2 p.m. All samples collected were analysed for solids content and, starting from the second sampling period, the detection of *Ascaris* eggs was performed. However, starting from day 17, samples were collected over a vertical profile and the depth of the profile was measured. The vertical profile was divided into three layers, top, middle and bottom. Each layer was analysed for the total solids and *Ascaris* eggs content.

Figure 3.4. Anaerobic Pond Sludge Transported to Drying Beds using an Excavator

EXPERIMENTAL PROGRAM II: COMPOSTING

3.6. Introduction

The major purpose of this study was to examine the effect of a simple, low technology and cheap sludge treatment process, namely composting, on the fate of *Ascaris* eggs. Passive composting technology was selected to be the type of composting process tested in this study. Sludge used in this study was primary filter pressed sludge, from the West Alexandria sewage treatment plant. Bulking agents used were agricultural wastes. In addition, cement dust by-pass was added to the sewage sludge at different concentrations, ranging from 0% to 50%, and its effect on the decomposition process and *Ascaris* eggs was studied. A period of 4 months of composting has been monitored, two months for the fermentation phase and two months for the maturation (curing) phase.

3.7. Treatment Plant Description & Sampling Locations

3.7.1. West Alexandria Sewage Treatment Plant

The West Alexandria sewage treatment plant (WTP) began operation in 1993. It has a design capacity of 186 million litres per day (Ml/d), with 285 Ml/d peak, and serves the West Zone of the City of Alexandria. Unit processes and operations at the WTP include coarse screening, influent pumping, grit removal, intermediate screening, primary clarification, scum removal, sludge pumping and mechanical dewatering facility (MDF).

Raw sewage entering the WTP is lifted by pumps in the influent pumping station, which includes an influent channel, eight screen channels, four mechanical screens, a distribution channel and five raw sewage pumps. Grit removal and intermediate screening operations take place at the plant headworks. A total of nine aerated grit chambers were constructed. After the grit is removed, wastewater flows through manually cleaned bar racks to Parshall flumes, which measure the flow received at the headworks. Flow from the headworks is directed to eight rectangular clarifiers through a distribution channel with submerged gates. A manually operated weir gate is available for bypassing flow in excess of the peak design flow. Solids that settle to the bottom of the clarifiers are collected and pumped out of the units to the Mechanical Dewatering Facility (MDF) for thickening. Flow from the primary clarifiers is collected in an effluent channel and piped to the effluent junction structure. From this structure, the effluent is discharged to the main basin of Lake Maryout through an open channel. The primary influent bypass is also connected to this structure in case of emergency.

Primary sludge is dewatered at the MDF, using belt filter presses, and loaded into trucks for transport to Site 9N for agricultural use. The sludge storage facility consists of two circular sludge equalisation tanks, each 13m in diameter. In an effort to reduce the production of hydrogen sulphide, the MDF is operated so that the tanks are emptied each day. The sludge equalisation tanks are equipped with air diffusers to keep the sludge mixed and maintain aerobic conditions. Sludge transfer pumps convey the sludge to eighteen belt filter press feed pumps, which pump the sludge to twelve belt filter presses, each 2m wide. The average feed sludge solids concentration is 4%, and the resulting sludge cake solids content averages 29.3%. The dewatered sludge is discharged to three conveyor belts and transferred to a discharge hopper, and from there to trailer trucks. Approximately 30 truckloads of dewatered sludge are transported daily to site 9N, an average of 22 metric tons on a wet weight basis. Polymer is used as a conditioning material to improve the dewaterability of the sludge. The MDF includes a polymer storage and feed system. This consists of a dry polymer storage area, four polymer feeders, four polymer mixing and agitating tanks and four polymer storage tanks.

3.7.2. Sampling Procedure & Sludge Characterisation

A loaded truck was diverted from site 9N to a location near the Cairo-Alexandria desert road at about 57 km from Cairo. This site was allocated for the composting trials. Approximately 20 tons of belt filter pressed sludge was available for the pilot scale work. Three samples were collected randomly from the front, middle and back portions of the batch and mixed thoroughly. A representative sample of the mixture was taken for full physicochemical characteristics and *Ascaris* content.

3.8. Materials and Methods

3.8.1. Materials

3.8.1.1. Primary sludge (S)

Belt filter pressed primary sludge from the West Alexandria sewage treatment plant was transported to the site of the pilot studies. Filter pressed sludge was used in this study, and the physicochemical composition is presented in **Table 3.4**. The sample was positive for viable *Ascaris* eggs.

3.8.1.2. Agricultural wastes (BA)

Fennel and basil wastes were collected from a Factory located in 6th of October Industrial zone, Giza Governorate. **Table 3.4** shows the physicochemical analyses of the fennel and basil wastes.

3.8.1.3. Cement dust (C)

Cement dust was obtained from the cement factory at Helwan, Cairo Governorate. The chemical analysis of the cement dust is presented in **Table 3.4.**

3.8.2. Experimental Procedures

3.8.2.1. Composting of sewage sludge, agricultural wastes and cement dust

The aim of this experiment was to study the effect of using a cheap, simple and low technology sludge treatment process, namely composting, while using different cement dust concentrations added to sewage sludge and bulking agent, on the viability of *Ascaris* eggs and the final compost quality.

Table 3.4. Main Physical and Chemical Characteristics of the Raw Materials Used

Parameter	Waste Type			
	Sewage Sludge	Fennel	Basil	Cement dust*
Physical characteristics				
pH	6.09	-	-	12.49
Density (kg/m^3)	1080	-	-	-
Moisture content (%)	20.413	6.6	7.4	0.020
Total dry solids (%)	79.587	93.4	92.6	99.98
Chemical characteristics				
Chemical Oxygen Demand (COD), mg/kg	89574	-	-	-
Biochemical Oxygen Demand (BOD_5), mg/kg	32766	-	-	-
Total Nitrogen (%)	3.4494	0.8983	0.9790	0.0045
NH_3-N (mg/kg)	57	-	-	-
NO_3-N (mg/kg)	0	-	-	-
Phosphorus (%)	1.953	-	-	0.0033
Potassium (%)	0.251	-	-	0.1227
Organic Matter (%)	75.96	78.29	75.96	-
Organic Carbon (%)	44.06	45.41	44.06	-
C/N ratio	12.8:1	50.6:1	45.0:1	-
Heavy metals (ppm/dry wt. basis)				
Iron	22180	-	-	520
Manganese	50	-	-	48
Copper	239	-	-	76
Zinc	804	-	-	73
Lead	789	-	-	159
Cadmium	22	-	-	17
Nickel	121	-	-	72
Chromium	134	-	-	-
Mercury	15	-	-	-

* CaO & $CaCO_3$ % in cement dust is 43% and 20%, respectively.

Sewage sludge (S), agricultural wastes (BA) and cement dust by-pass (C) were used in the production of compost. The sewage sludge, and agricultural wastes used as bulking agents, were mixed at certain proportions in order to adjust the C/N ratio of the mixture to about 25:1. Then, to some mixtures, cement dust by pass was added at concentrations ranging from 0% to 50% of the dry weight basis of the sludge. Ten piles were made for the various treatments in two phases, four piles and six piles for phases 1 & 2, respectively, as follows:

Phase 1

1. S + BA (windrow pile)
2. S + BA (passive pile)
3. S + BA + 30% C
4. S + BA + 40% C

Phase 2

5. S + BA + 10% C
6. S + BA + 20% C
7. S + BA + 25% C
8. S + BA + 35% C
9. S + BA + 50% C
10. S + 30% C

The windrow and passive piles were constructed mainly to be a reference point for the treatment process in general. The windrow and passive piles were formed of a mixture of sludge and agricultural wastes only, without cement dust. The difference between the windrow and passive piles was the ventilation pipes that were laid underneath the passive pile, but not the windrow pile. Phase 2 piles were constructed three weeks after the start-up of phase 1 piles and, accordingly, the calculations for the waste materials weights used to reach a favourable C/N ratio differ. **Table 3.5** shows the characteristics of the waste materials used in the C/N ratio calculations for phases 1 & 2 and **Table 3.6** shows the composition and weights of the mixed wastes used for phases 1 & 2 and their calculated equivalent C/N ratios. The ten treatments were carried out for about four months, two months for the fermentation stage and another 2 months for the maturation stage. The process used for forming the piles is described as follows:

i. Passive composting was selected to be the type of composting process for all piles (except the windrow pile), due to the ease of operation, minimal attention for aeration (self aerated through underlying ventilation pipes) and cheapness relative to aerated static pile composting. For all piles, the design of compost pile shown in **Figure 3.5** was adopted:

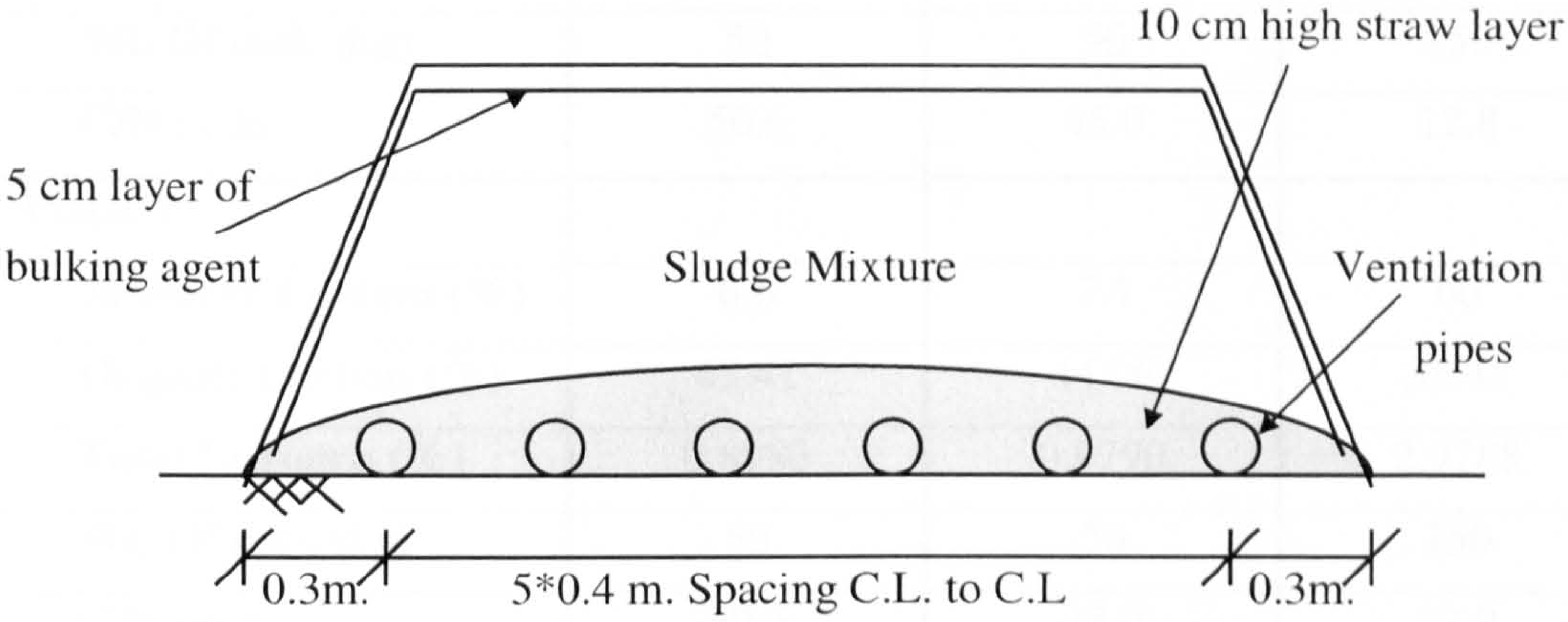

Figure 3.5. Cross Section through Compost Piles

ii. The initial dimensions of the piles were 2.5(L) * 2.2(W) * 0.9 to 1.1(H) in metres. The details of the pipes used for ventilation in each pile are:

- PVC pipes
- 6 perforated pipes.
- 10 cm diameter.
- 2.2 metres long.
- Perforated with two rows of 1cm diameter holes.
- 30 cm spacing between holes within the rows.

iii. A concrete platform (1.5*1.5m) was prepared on site, where the sludge was mixed thoroughly manually to maintain homogeneity with the bulking agent and the cement dust, as shown in **Figure 3.6**. Water was splashed on the mix to maintain moisture content of about 50 to 60%. Pipes were laid on the ground according to the design spacing, and covered with about 10 cm straw layer. The mixture to be composted was piled on top of the straw, with the designed dimensions as shown in **Figure 3.7**. Finally, the pile was covered with a 5 cm layer of bulking agent, to act as an insulating layer, as well as to prevent any foul smells and flies from gathering on the pile.

Table 3.5. Characteristics of the Waste Materials Used in C/N Ratio Calculations

Parameter	Fennel	Basil	Sewage sludge
Phase 1			
Moisture Content (%)	6.6	7.4	71.5
Organic Carbon (%)	45.41	44.06	44.06
Total Nitrogen (%)	0.8983	0.9790	3.4494
Wt. Of sack (kg)	50	50	150
C/N ratio	50.6	45.0	12.8
Phase 2			
Moisture Content (%)	6.6	7.4	60
Organic Carbon (%)	45.41	44.06	38.45
Total Nitrogen (%)	0.8983	0.9790	2.9788
Wt. Of sack (kg)	50	50	150
C/N ratio	50.6	45.0	12.9

iv. Due to the high ambient air temperatures in Egypt, the piles were splashed with water every second to third day, to maintain the moisture content required for microbial activity, and pipe ends kept clear daily, to maintain the air circulation.

v. At the end of the fermentation phase, the ventilation pipes were removed and the piles were mixed and moistened, and then covered with a 5 cm bulking agent layer.

Regular measurements were taken during the composting period, including temperatures within the pile **(Figure 3.8)** and CO_2 evolution within the pile **(Figure 3.9)** at three points within the pile, along the two sides at about 30 cm from the surface layer and in the middle of the pile at about 20, 40 and 60 cm from the surface layer, respectively. However, due to the microbial activity and decomposition of organic matter, there was a considerable volume reduction over a relatively short period. Hence, the measurements taken on the piles were restricted to one reading for each parameter at each point in the pile. **Figure 3.10** shows the final layout of the 10 piles at the site.

Table 3.6. Composition and Weights of Waste Materials for Phases 1& 2 and their Equivalent C/N Ratios

Waste Material	Waste Weight (kg)	Dry Weight (kg)	Carbon Weight (kg)	Nitrogen Weight (kg)	C/N Ratio
Phase 1					
Fennel	50	46.7	21.21	0.4195	50.6
Basil	50	46.3	20.40	0.4533	45.0
Sludge	150	42.8	18.84	1.4746	12.8
Total	**250**	**135.8**	**60.44**	**2.3474**	**25.7**
Phase 2					
Fennel	50	46.7	21.21	0.4195	50.6
Basil	50	46.3	20.40	0.4533	45.0
Sludge	150	60.0	23.07	1.7873	12.9
Total	**250**	**153.0**	**64.68**	**2.6601**	**24.3**

Figure 3.6. Manual Mixing of Sludge, Bulking Agent and Cement Dust

Figure 3.7. Compost Pile Laid on Top of Pipes Covered with Straw

Figure 3.8. Recording Temperatures within the Piles

Figure 3.9. Recording CO_2 within the Piles

Samples of the sludge mixture were collected from the piles at start up and at two weeks, one month, two months and finally after four months of composting. Three samples were taken from both sides and the middle of each pile at a depth of about 20 cm and 40 cm from the surface layer, respectively. At each sampling location, after reaching the required depth with a shovel, a bucket was filled with the organic matter, mixed thoroughly and a representative sample taken. The remaining organic matter was placed back in the pile and covered with bulking agent. All samples were analysed for physicochemical parameters and *Ascaris* eggs content. Physicochemical analysis included pH, organic matter, organic carbon, total nitrogen, Ammoniacal nitrogen, nitrate and C/N ratio. In addition to these parameters, the heavy metals content was also analysed for but only on the initial and final samples.

Figure 3.10. Layout of piles

CHAPTER FOUR: RESULTS & DISCUSSION

4.1. Experimental Program I: Anaerobic Pond Sludge Applied on Drying Beds

4.1.1. Anaerobic Pond Sludge

4.1.1.1. Sludge accumulation, distribution & volume

The pattern of sludge accumulation in the anaerobic pond is shown in **Figure 4.1.** Values shown in the figure indicate the depth of the sludge layer in metres at each point.

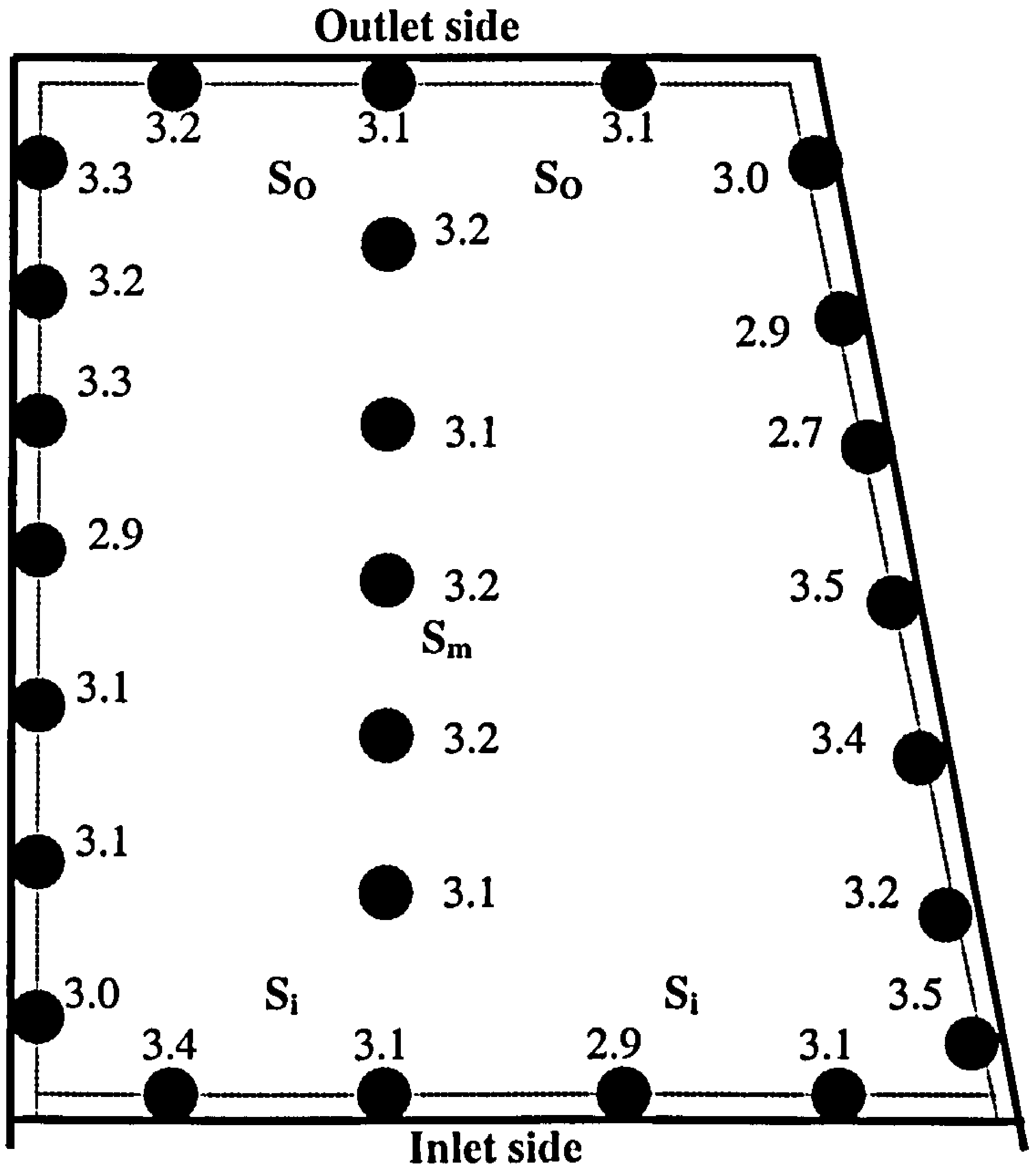

Figure 4.1. Sludge Depth in metres in the Anaerobic Pond

(Si, Sm, So; Samples collected from inlet, middle & outlet sides, respectively)

From the measurements taken on the anaerobic pond, it is very clear that the sludge level was very high, exceeding the design expectation and operating standards of the treatment plant. The sludge depths at the four sides and middle of the pond were as follows:

1. The average sludge depth at the inlet side of the pond was approximately 3.0 metres.
2. The average sludge depth at the outlet side of the pond was approximately 3.1 metres.
3. The average sludge depth at the middle of the pond was approximately 3.2 metres.
4. The average sludge depth at the sidewalls was approximately 3.0 metres.

The maximum depth recorded was 3.5 m at the right hand side wall, which was the inlet side. However, in general, there was a homogenous distribution of sludge over the pond.

From the sludge distribution and measurements at different locations of the pond (Figure 4.1), the approximate volume of sludge could be calculated on the basis of an average of 3.1 metres of sludge.

V_{sludge} = anaerobic pond surface area * sludge depth

= {(17.5 + 25.4) * 36.5 / 2} * 3.1

= **2428 m^3 (wet weight basis)**

V_{sludge} (dry weight basis) = wet weight basis * (average total dry solids)/100%

Average total dry solids = (18.756 + 16.113 + 16.879) / 3

= 17.25 %

Therefore V_{sludge} (dry weight basis) = 2428 * 17.25 / 100

= **419 m^3 (dry weight basis)**

Therefore volume of sludge accumulated / capita = 2428000/(8500 capita * 6 yrs.)

= **47.6 litres/year.**

As is well known, anaerobic ponds have the ability to store sludge for long periods, and in the case of the Mit Mazah anaerobic pond a sludge volume of about 2430 m^3 wet weight basis (compared to a total pond volume of about 3135 m^3) accumulated from 1992 to 1998 in one pond. This means that the sludge occupied about 78% of the total volume of the pond.

The annual sludge accumulation rates estimated from the mean sludge depth (3.1 m) and sampling period (1992 to 1998) was 44 cm/year. The rate of deposition is very high compared to the values given in the literature for a similar climate. According to Hindiyeh (1995), the sludge accumulation rates for anaerobic ponds in Jordan were 29, 35 and 22 cm/year at three different ponds.

4.1.1.2. Raw wastewater & sludge characteristics

It was very important to analyse the raw wastewater entering Mit Mazah WSP, for both physicochemical characteristics and *Ascaris* content, to give an indication of the wastewater strength and the quality of accumulated sludge in the anaerobic pond. **Table 4.1** shows the physicochemical analysis of the composite sample of raw wastewater collected from the inlet sump, compared with the average composition of wastewater in Amman, Jordan and typical strong domestic wastewater.

a. Wastewater

Usually, wastewater strength is measured in terms of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD). As shown in Table 4.1, raw wastewater entering Mit Mazah WSP is classified as very strong, compared with reported strength classifications in the literature. BOD_5, COD and total dissolved solids (TDS) values for Mit Mazah raw wastewater were 887, 1537 and 1067 mg/l, respectively, compared with the expected 400, 1000 and 850 mg/l values for strong wastewater, respectively. However, Mit Mazah wastewater analysis is very similar to the average composition of wastewater in Amman, Jordan. This is due to the fact that in villages and rural areas water is very limited, and the average water consumption would average 50 l/d per person in Egyptian villages. From the analysis, the iron content seems to be a problem in the wastewater, especially for a village having no industrial waste discharges. According to the Cairo Wastewater Organisation, the possible justification for the high iron content could be from the water distribution network, that has been badly corroded due to ageing Nevertheless, a high content of iron is beneficial to the soil, especially sandy soils. Regarding the parasitological content, *Ascaris* eggs were detected in the samples, and were found to be viable.

Table 4.1 Physicochemical Analysis of Influent Wastewater to Mit Mazah WSP

Parameter	Unit	Raw Wastewater		
		Mit Mazah	Jordan [a]	Typical [b]
Colour	-	grey		
pH-value	-	6.9		
Oil & grease	mg/l	49		
Biochemical Oxygen Demand (BOD_5)	mg/l	887	770	400
Chemical Oxygen Demand (COD)	mg/l	1537	1830	1000
Suspended solids	mg/l	438	900	350
Total dissolved solids	mg/l	1067	1170	850
Sodium	mg/l	140		
Potassium	mg/l	75		
Calcium	mg/l	73		
Magnesium	mg/l	25		
Sulphate	mg/l	50	90	50
Phosphate	mg/l	12.5	25	15
Nitrate	mg/l	49		
Sulphide	mg/l	2.5		
Phenol	mg/l	<0.005		
Ammonia-N	mg/l	1.8		
Iron	mg/l	7.74		
Manganese	mg/l	0.28		
Copper	mg/l	<0.01		
Chromium	mg/l	<0.01		
Lead	mg/l	0.15		
Nickel	mg/l	<0.01		
Zinc	mg/l	0.08		
Titanium	mg/l	<0.01		
Total heavy metals	mg/l	8.25		

a Average composition of wastewater in Amman, Jordan.
Source: Pescod (1992), Al-Salem (1987).
b Typical composition of untreated strong domestic wastewater.
Source: Metcalf & Eddy (1991).

b. Sludge

The sludge from the anaerobic pond was black in colour, granular in texture, compact and had no objectionable odour. **Table 4.2** shows the physicochemical analysis of samples collected from the anaerobic pond sludge at the inlet side (Si), middle (Sm) and outlet side (So) of the pond, respectively, compared to the normal ranges referred to in the literature. In general, all samples showed very similar concentrations, indicating the homogeneity of the sludge in the pond. All the sludge samples had a neutral pH ranging from 7.2 to 7.4. The moisture content of the sludge was between 80% and 84%. These values are similar to those measured in the work done previously in Jordan by Hindiyeh (1995). According to Hindiyeh (1995), the pH of the anaerobic pond sludge was in the range of 6.5 to 8.4 and moisture content was between 78 and 86%.

The average dry solids content of the sludge samples was approximately 18%, ranging from 16% to 19.5%. The total volatile solids content (TVS) averaged approximately 47% of the total solids, as shown in Table 4.2. With regard to the macronutrients, the nitrogen, phosphorus and potassium contents of the total solids content in the sludge samples averaged approximately 4.0%, 1.5% and 0.275%, respectively. From these analysis and by comparison with a typical digested sludge physicochemical analysis, it is very clear that the Mit Mazah sludge was very well digested and compacted due to the nature of the operation of the stabilisation pond.

Regarding the *Ascaris* content in the anaerobic pond sludge, in all the samples collected no viable *Ascaris* eggs have been detected. This was expected, due to the age of sludge and the extensive anaerobic digestion process it went through for more than 6 years. This presents one of the main benefits of stabilisation pond treatment process.

Table 4.2. Physicochemical Analysis of Anaerobic Pond Sludge in Mit Mazah WSP

Parameter	Unit	Si	Sm	So	Typical*
pH value	-	7.2	7.4	7.4	6.5-7.5
Moisture content	%	83.887	80.464	81.244	88-94
Total dry solids (TS)	g/kg	161.13	195.36	187.56	
Total dry solids	%	16.1	19.5	18.7	6.0-12.0
Total volatile solids (TVS)	% of TS	45.021	49.560	47.711	30-60
Bicarbonate	% of TS	0.308	0.498	0.594	
Total K-nitrogen	% of TS	3.944	4.055	4.065	1.6-6.0
Total phosphate	% of TS	1.789	1.651	1.451	1.5-4.0
Potassium	% of TS	0.268	0.275	0.284	0.0-3.0
Iron	% of TS	3.273	3.410	3.294	3.0-8.0

* Typical chemical composition of digested sludge, Source: USEPA (1979).

Si, Sm and So: Samples collected from the inlet, middle and outlet sides of the anaerobic pond, respectively.

4.1.2. Drying Bed Trials

4.1.2.1. Weather conditions and sludge temperature

When liquid sludge is applied to a drying bed, dewatering takes place by drainage during the first days, followed by evaporation. During the drying process, dewatering and evaporation processes are ongoing, yet with slower rate. However, in the later stages, evaporation is the mechanism of drying that becomes most important, and is greatly affected by weather conditions, including wind, humidity, air temperature and solar radiation. Moreover, the weather conditions, especially air temperature and the sun intensity and duration, affect the sludge temperature and, in turn, influence the drying process. It is important, therefore, to discuss the weather conditions and sludge temperature in the same section for their relationship. **Appendix 4.1** shows the data collected on the drying beds during the drying period.

According to Pescod (1971), drying beds are suitable for tropical (hot climate) countries due to the favourable weather conditions for the drying process. Fortunately, Egypt is one of the countries blessed with favourable conditions for the use of natural dewatering processes that not only dry sludge but also help in inactivating the most persistent parasites. The high sunshine duration and intensity, more than 4000 hrs/year according to Hossam et al. (1990), throughout the year are great assets. As mentioned in section 3.3.2.1 (section c), the air temperature and sludge temperature from the three beds were recorded every day during the study period, and the data for sunshine and rainfall during the period of study were obtained from the National weather station in Cairo. **Table 4.3** summarises the prevailing climatic conditions during the winter and summer study periods, respectively. An Excel package was used for the data analyses and figures of the daily temperature and sludge temperature data.

Figures 4.2, 4.3 and 4.4 show the ambient air temperature levels during the winter applications; first trial (October and November months, 1997) and second trial (December 1997 and January 1998), and summer application (July and August 1998), respectively. It was very important to record the air temperatures during the mornings and afternoons, due to the variation in temperature levels, as shown in Figures 4.2 to 4.3 and Appendix 4.1. There was an increase between the mornings and afternoons, of 4 to 6°C, and 4 to 7°C for the first and second trials of the winter season, respectively.

However, for the summer trial, an increase of 6 to 9°C was recorded between the morning and afternoon.

Table 4.3. Weather Conditions during the Drying Bed Trials

Month (Unit)		Air temperature (°C)*	Sunshine (hours)	Rainfall (mm/month)
Winter Season				
October	**Average**	32.2	8.7	0
	Maximum	35	9.0	0
	Minimum	29	8.5	0
November	**Average**	26.3	7.3	8
	Maximum	28	8.0	12
	Minimum	24	6.8	0
December	**Average**	21.1	6.6	45
	Maximum	27	7.0	52
	Minimum	14	6.0	35
January	**Average**	20	5.5	40
	Maximum	24	5.8	55
	Minimum	17	5.3	28
Summer Season				
July	**Average**	36.6	12.2	0
	Maximum	40	12.3	0
	Minimum	32	11.9	0
August	**Average**	40	12.3	0
	Maximum	43	12.5	0
	Minimum	36	12.0	0

* Values given for the air temperature are based on the afternoon readings only.

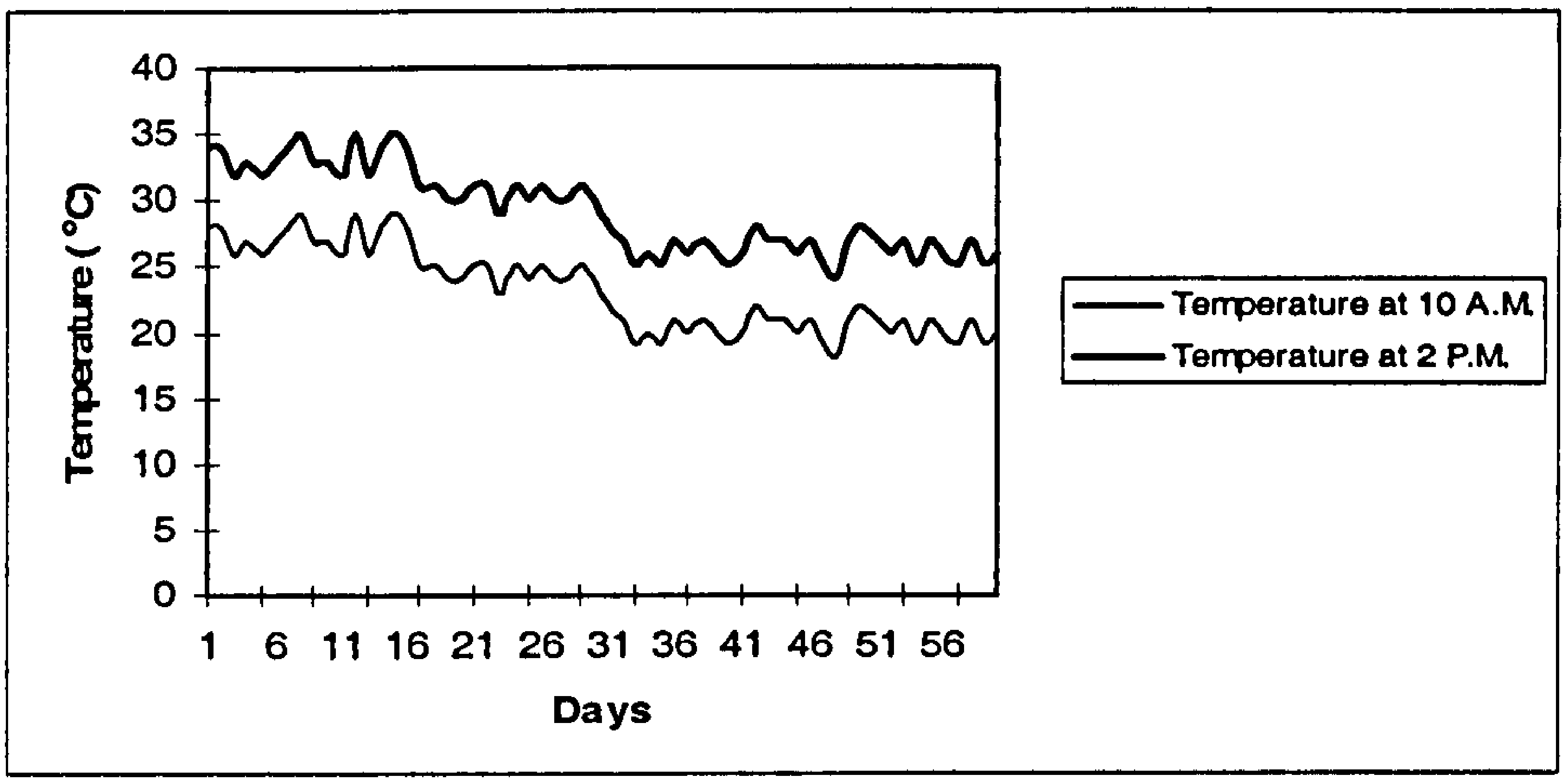

Figure 4.2. Air Temperature for First Application during Winter Season (October and November 1997)

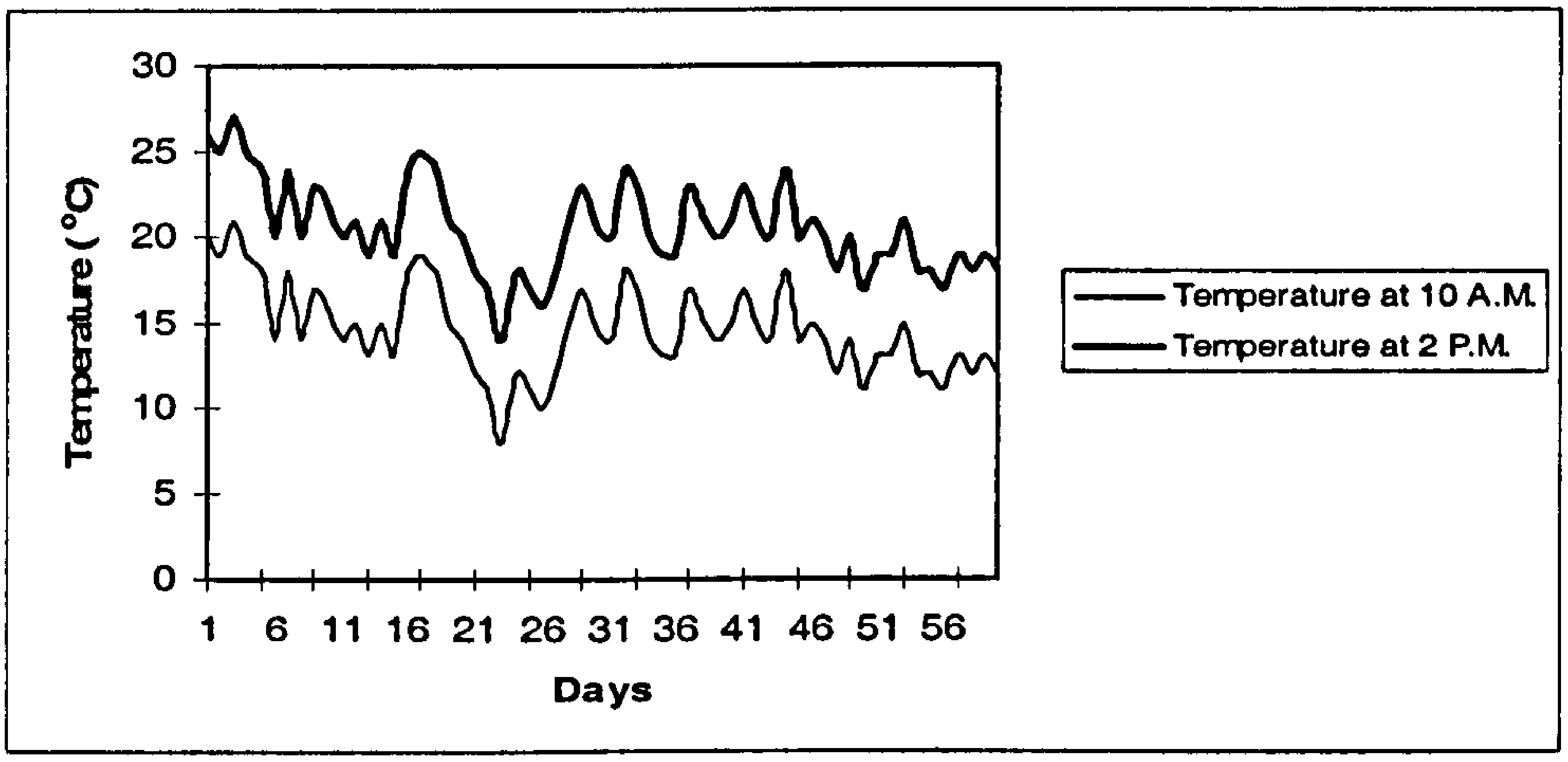

Figure 4.3. Air Temperature for Second Application during Winter Season (December and January 1997/98)

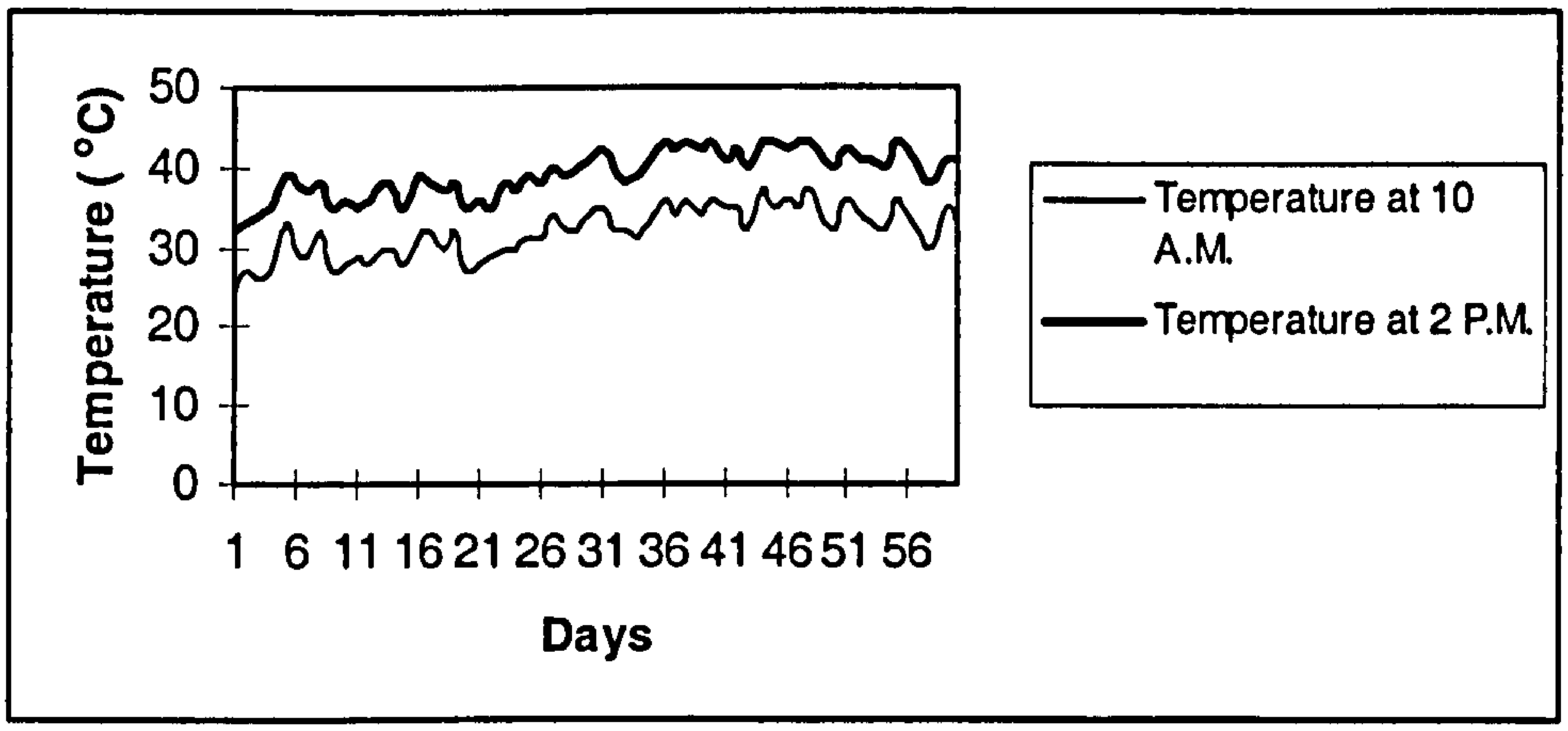

Figure 4.4. Air Temperature for Application during Summer (July and August 1998)

Table 4.4 shows the sludge temperature during the winter and summer trials for the three drying beds. In general, the three drying beds had similar temperatures, with a slight variation of 3°C. With regard to the difference between the air and sludge temperatures, it was noticed that during the winter trials the sludge temperature was less than the air temperature, while during the summer trial the sludge temperature was higher than the air temperature. During the winter season, the sludge temperatures for the first and second trials showed a maximum variation of 5°C and 6°C less than the air temperature, respectively. However, during the summer trial the maximum variation was recoded to be 4°C more than the ambient air temperature.

4.1.2.2. Configuration of drainage medium

Most of the water content leaves the sludge by drainage through the sludge mass and supporting drainage medium. The configuration and depth of layers should affect the drainability and thus the duration of the drying process. This is mainly influenced by the sand layer, and Metcalf and Eddy (1991) recommends that the sand layer should not exceed 30 cm, otherwise the dewatering process will be retarded. In chapter 3, Figures 3.2 & 3.3 show the cross section of the drying beds used in this study. The depth of the sand layer was different for drying beds 1, 2 and 3, and was 10, 15 and 20 cm., respectively, during the winter trials. However, during the summer trial the depth of the sand layer was 20 cm. for the three beds. The alteration in sand layer depth was mainly to study the change in the total solids content and sludge thickness with time, which is discussed in the next section (section 4.1.2.3).

Table 4.4. Sludge Temperature during the Drying Bed Trials

Month (unit)		Temperature (^oC)*		
Winter Season First trial		Drying bed 1	Drying bed 2	Drying bed 3
October	Average	27.8	27.9	28.1
	Maximum	30	30	33
	Minimum	25	25	26
November	Average	22.2	21.2	22.2
	Maximum	26	25	24
	Minimum	20	19	20
Second trial				
December	Average	16.6	15.1	16.1
	Maximum	22	21	22
	Minimum	10	8	9
January	Average	15	14.2	15.4
	Maximum	19	18	20
	Minimum	12	11	12
Summer Season				
July	Average	40.1	40.1	40.7
	Maximum	45	45	47
	Minimum	37	37	37
August	Average	46.4	46.4	46.8
	Maximum	50	50	51
	Minimum	42	42	44

* Values given for the air temperature are based on the afternoon readings only.

4.1.2.3. Total solids and depth of sludge

As discussed in Section 3.3.2.1, the first sludge application during the winter was 25, 20 and 15 cm. for drying beds 1, 2 and 3, respectively. **Figures 4.5, 4.6 & 4.7** show the changes in percentage of total solids content with time for drying beds 1, 2 and 3, respectively. Vertical samples collected from the third sampling period were divided into 3 layers, top, middle and bottom. This will give clear figures of the total solids content in the bottom layers, as well as the effect on *Ascaris* viability (discussed in section 4.1.2.4).

The anaerobic pond sludge characteristics have been discussed in Section 4.1.1.2, and it was concluded that the sludge was at an advanced stage of stabilisation, due to the prolonged anaerobic digestion process during the 6 years period of accumulation. Accordingly, the dewaterability of the sludge applied on the drying beds was enhanced, due to the fact that the sludge matrix did not retain moisture and the water content tended to drain much easier than undigested sludge. With regard to the drying process, it was observed in general that sludge with the lowest initial solids content, and regardless of the sludge layer thickness, drained faster and a large quantity of the water was removed by drainage during the first week rather than by evaporation. In addition, thinner sand layers eased the drainage process and the beds started to produce filtrate in the first few days of drying. This has been shown in the first sludge application, where drying beds 1, 2 and 3 produced filtrate on days 2, 3 and 5, respectively, and lasted for 5, 4 and 3 days, respectively. Initial solids content of drying beds 1, 2 and 3 were 9.5%, 12.8% and 18.8%, which increased by approximately 13%, 11% and 9%, respectively in the first week. By the end of the drying period, the top sludge layer on drying beds 1, 2 and 3 lost about 79%, 76% and 72% moisture, and reached a final solids content of 88%, 89% and 91%, respectively. However, by the end of two months, the bottom layers contained lower solids content, ranging from 74% to 72%, 75% to 73% and 77% to 72%, for middle and bottom layers of drying beds 1, 2 and 3, respectively. Regarding the change in sludge thickness, **Figure 4.8** shows the change in sludge depth with time for the first sludge application. The sludge thickness decreased from 25, 20 and 15 cm, to 14, 12 and 8 cm, for drying beds 1, 2 and 3, respectively, within the two months drying period.

The second sludge application during the winter season experienced unfavourable weather conditions, except during the first week, as shown in Section 4.1.2.1. This affected the drying process and resulted in a much lower solids content sludge, by comparison with the first application. However, again the sludge with the lowest initial solids content, and regardless of the sludge layer thickness, drained faster and a large quantity of the water was removed by drainage. Again, the thinner sand layers eased the drainage process. Sludge applied on drying beds 1, 2 and 3 was 15, 25 and 25 cm., respectively and **Figures 4.9, 4.10 & 4.11** show the changes in percentage of total solids content with time for these drying beds. It was noticed that drying beds 1, 2 and 3 produced filtrate on day 2, 3 and 5, respectively, and lasted for 5, 4 and 3 days, respectively. The initial solids content of sludge on drying beds 1, 2 and 3 was 10.5%, 11.5% and 13.3%, which increased by approximately 20%, 17% and 15%, respectively in the first week. Starting from the second week of drying, until the end of the two months, the sludge on drying beds 1, 2 and 3 lost approximately 24%, 26% and 25% moisture, and reached final solids contents of 54%, 54.8% and 53%, respectively. This means that during the first week, due to the favourable weather conditions, moisture content lost was about 45%, 41% and 37% of the total moisture content lost during the two months drying period for drying beds 1, 2 and 3, respectively. Regarding the bottom layers, after the two months drying period, the solids content was lower than the top layers, as a result of not being in contact with the external weather conditions, and percentages ranged from 49% to 43%, 49% to 44% and 49.5% to 45.2%, for middle and bottom layers of drying beds 1, 2 and 3, respectively.

Regarding the change in sludge thickness, **Figure 4.12** shows the change in sludge depth with time for the second sludge application. The sludge thickness decreased from 15, 25 and 25 cm, to 9, 16 and 16 cm, respectively for drying beds 1, 2 and 3, respectively, within the two months drying period.

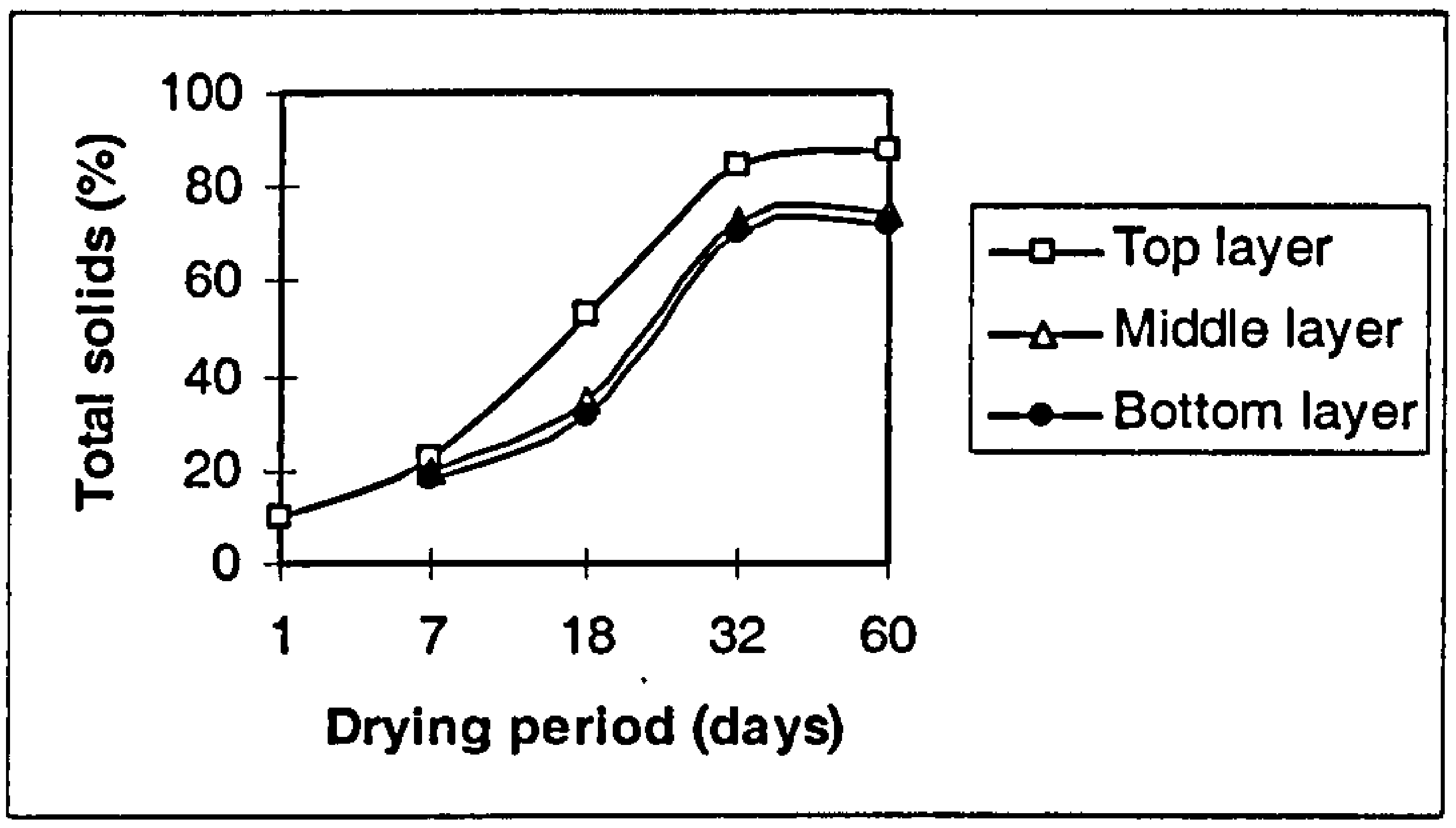

Figure 4.5. Changes in Total Solids Content with Time for Drying Bed 1 during Winter, First Application

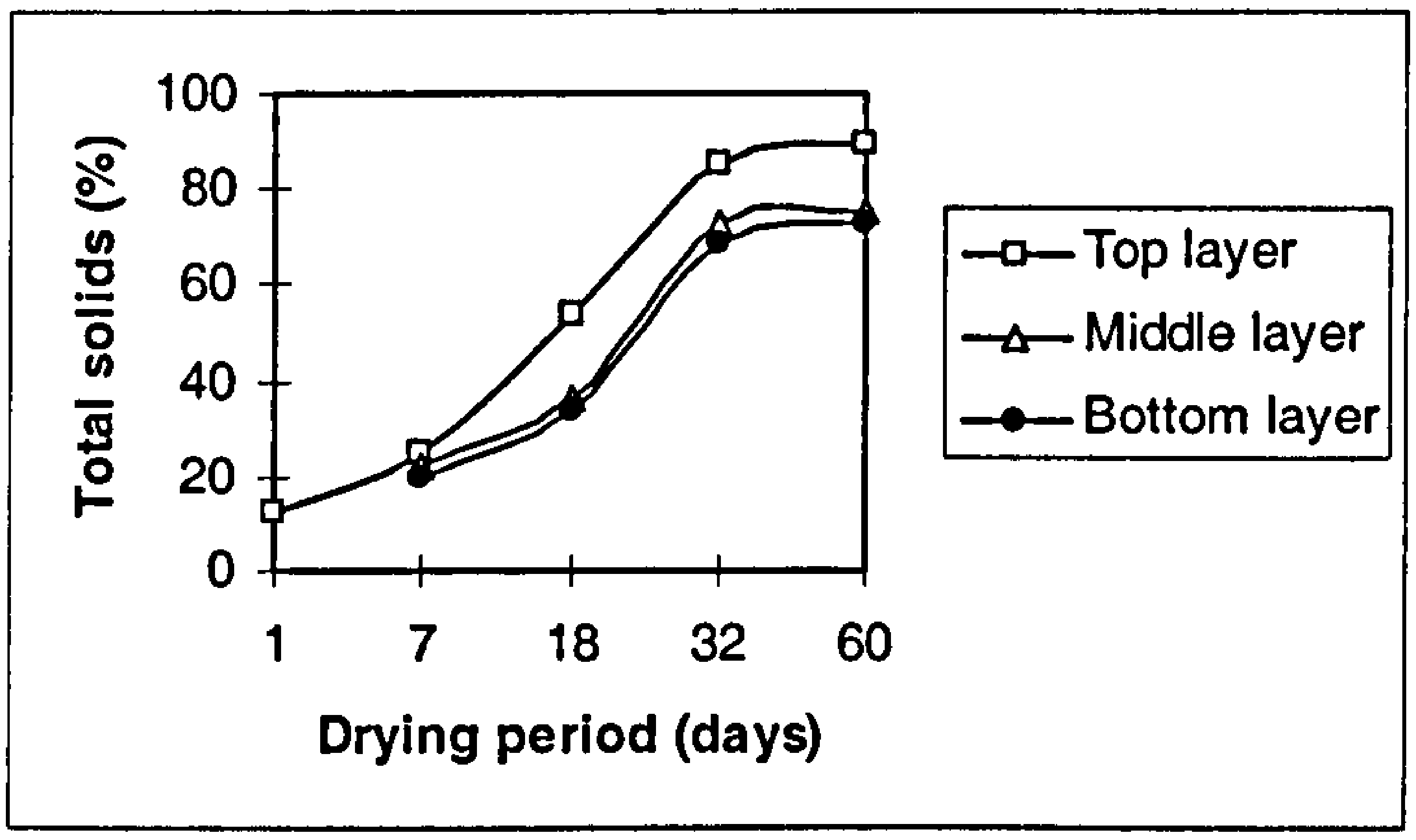

Figure 4.6. Changes in Total Solids Content with Time for Drying Bed 2 during Winter, First Application

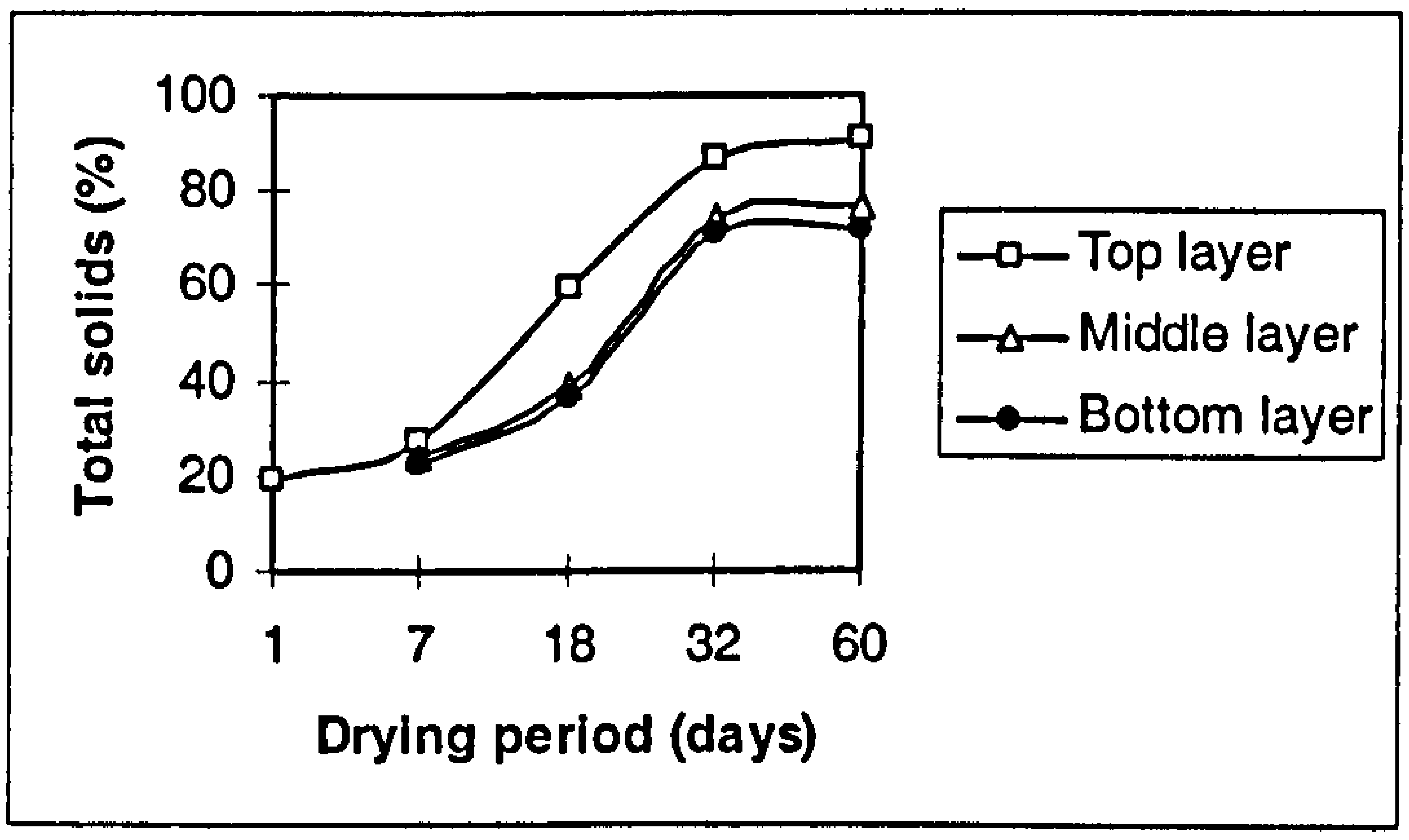

Figure 4.7. Changes in Total Solids Content with Time for Drying Bed 3 during Winter, First Application

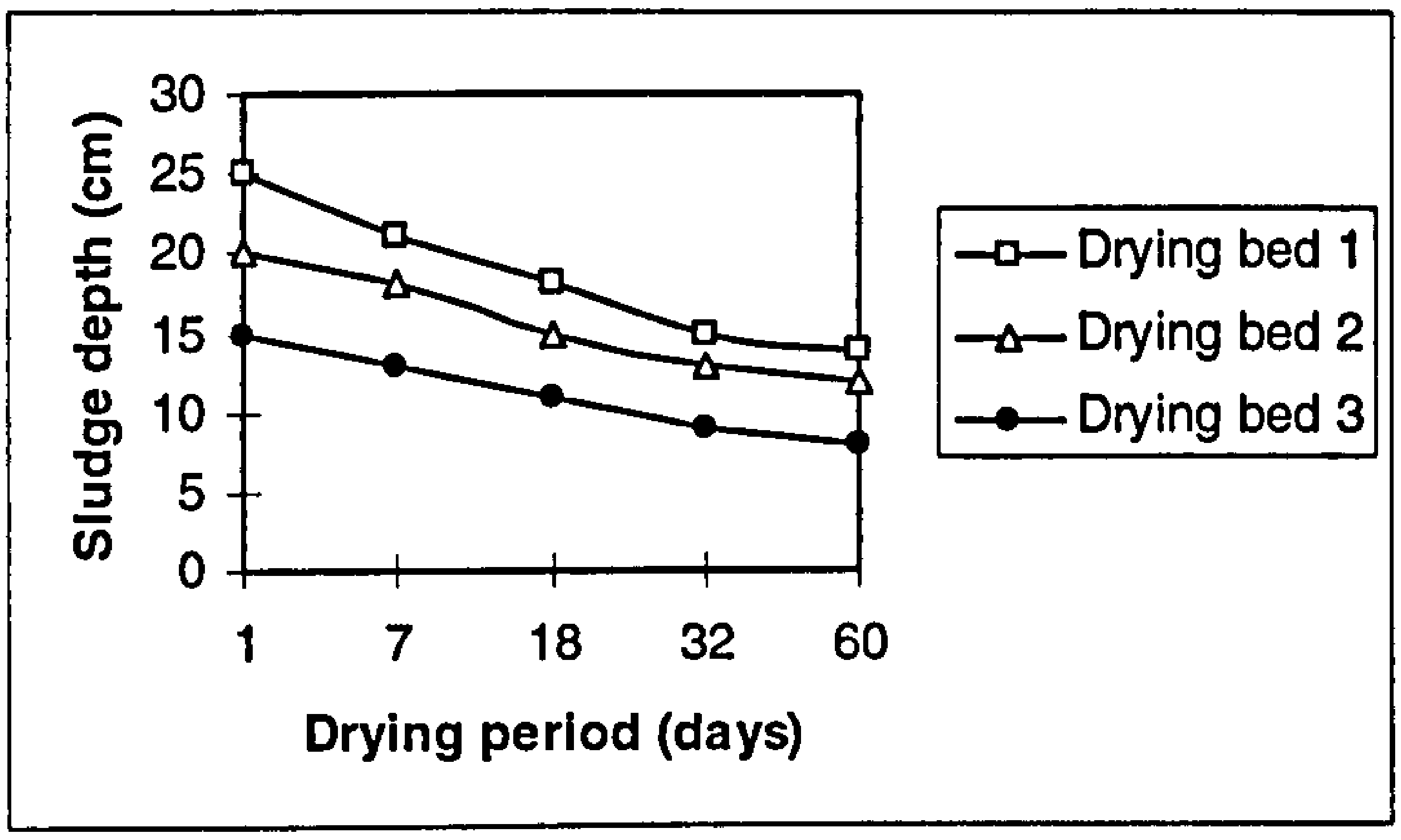

Figure 4.8. Changes in Sludge Depth with Time for Sludge applied on Drying Beds during Winter, First Application

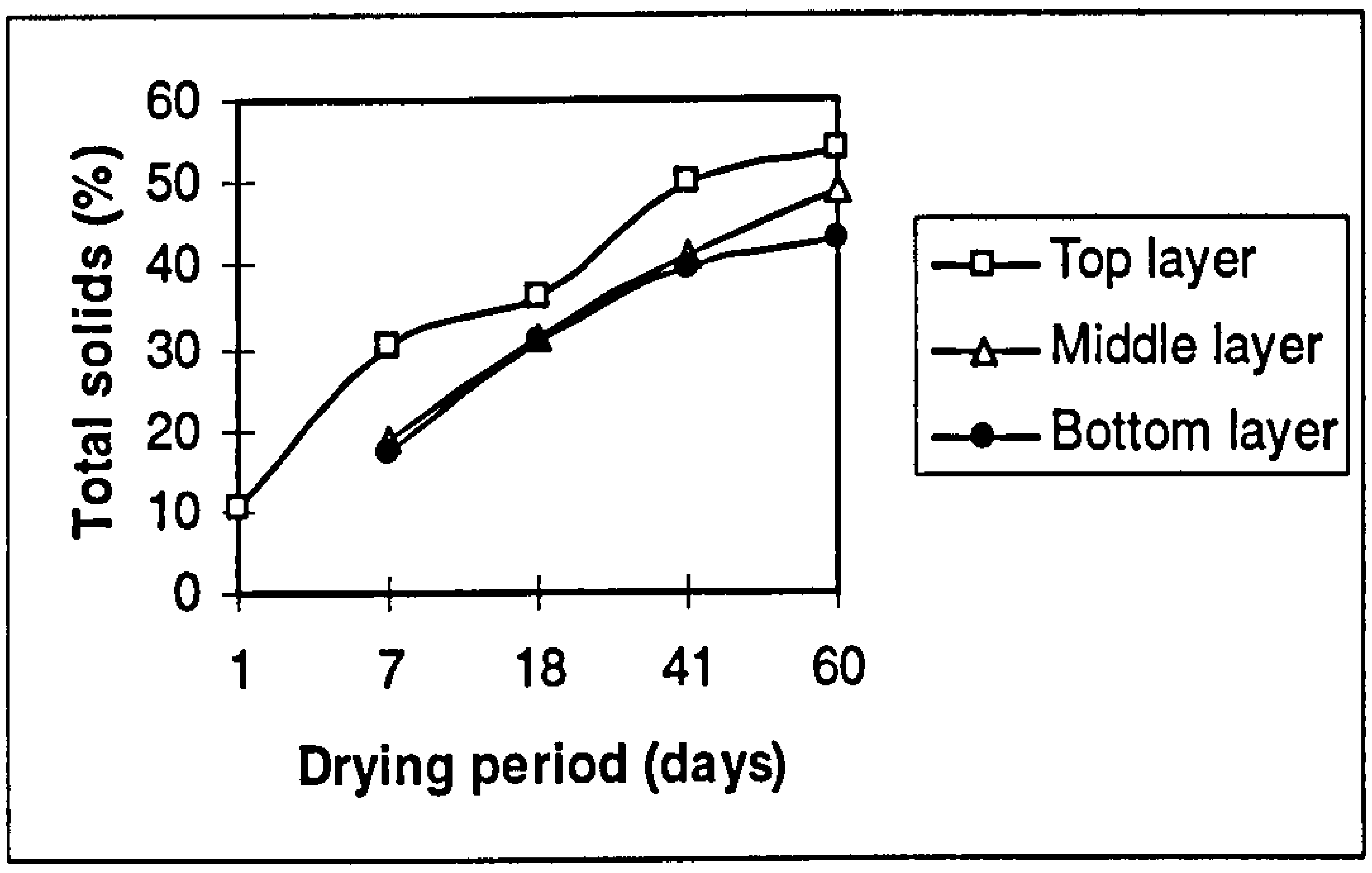

Figure 4.9. Changes in Total Solids Content with Time for Drying Bed 1 during Winter, Second Application

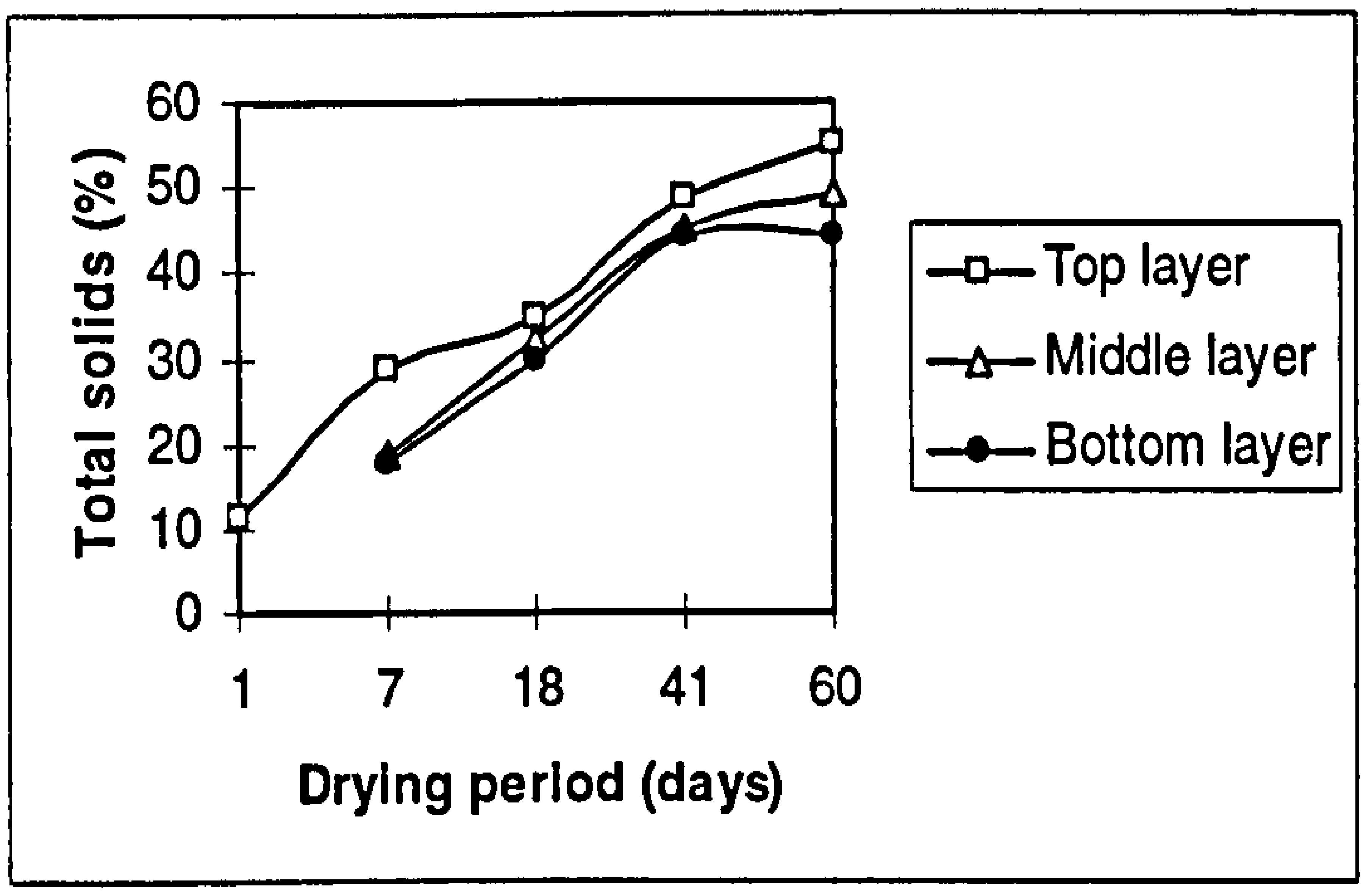

Figure 4.10. Changes in Total Solids Content with Time for Drying Bed 2 during Winter, Second Application

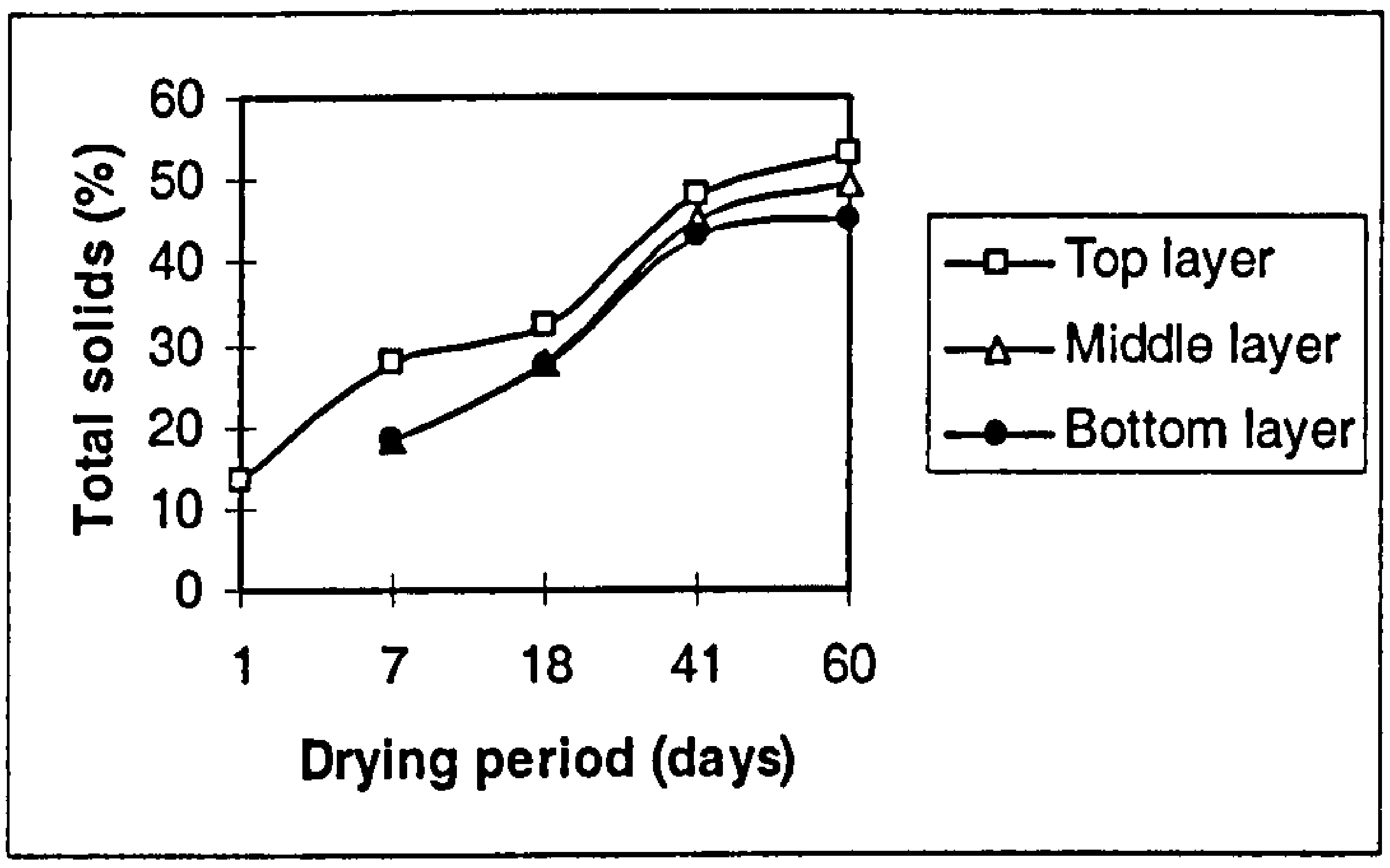

Figure 4.11. Changes in Total Solids Content with Time for Drying Bed 3 during Winter, Second Application

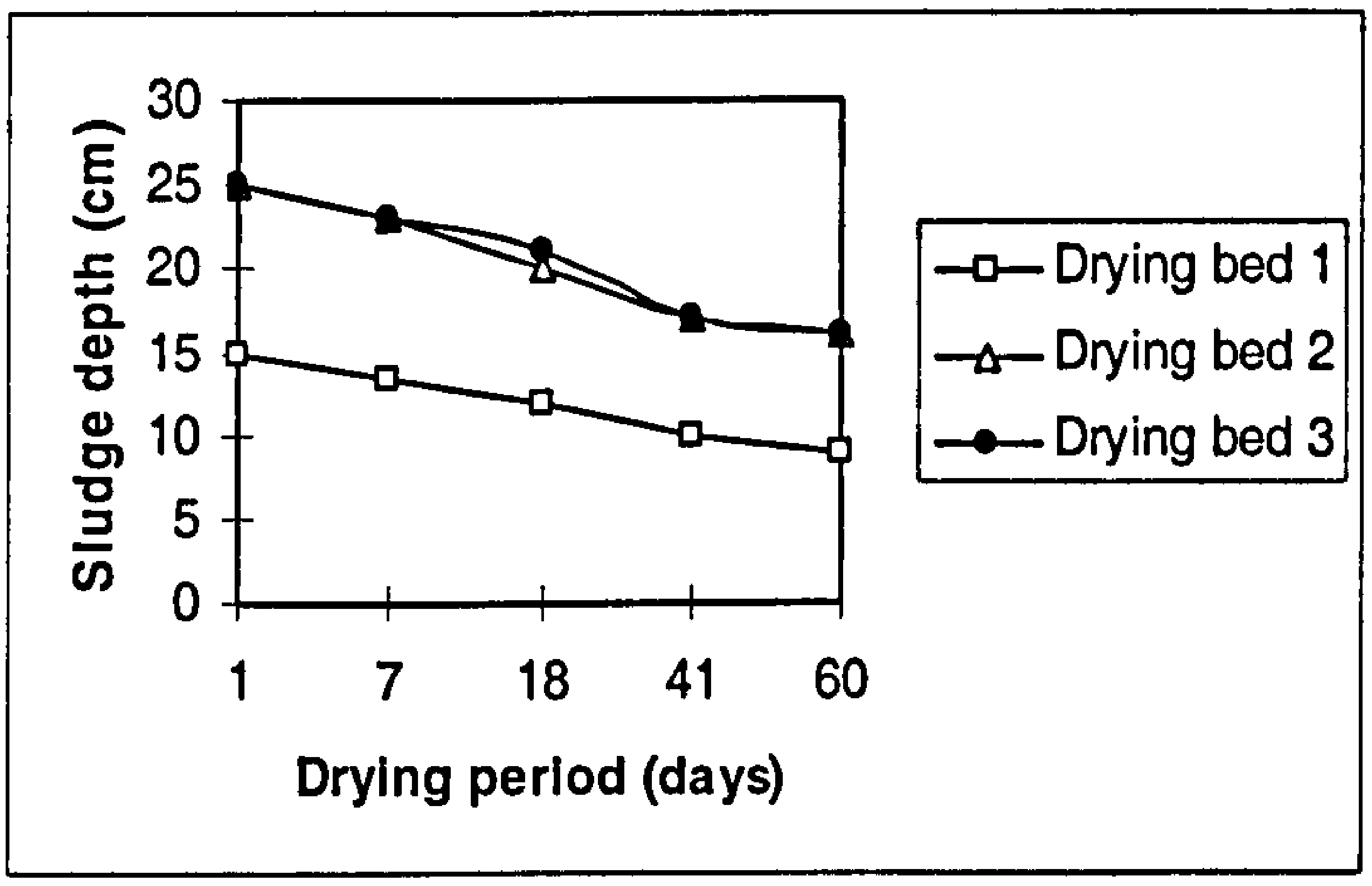

Figure 4.12. Changes in Sludge Depth with Time for Sludge applied on Drying Beds during Winter, Second Application

During the summer, sludge was applied onto the drying beds, in 15, 20 and 25 cm layers for drying beds 1, 2 and 3, respectively. The sand layer was maintained at a depth of 20 cm for the three drying beds. As discussed in Section 4.1.2.1, the weather conditions were favourable for the drying process, proved through the high loss of moisture during short drying periods. During the summer, the impact of drainage and evaporation processes was different from the winter application, due to the sunshine and high air temperatures. It was noted that both processes were ongoing simultaneously. Drying beds 1, 2 and 3 produced filtrate on days 2, 2 and 3, respectively, and lasted for 1 day. This indicates that some of the moisture content had evaporated before draining through the media, also supported by the percentage of solids content measured after 3 days of drying. **Figures 4.13, 4.14 & 4.15** show the changes in percentage of total solids content with time for drying beds 1, 2 and 3, respectively. The initial solids content of drying beds 1, 2 and 3 were 17.4%, 18.6% and 21.3%, which increased to 24.7%, 26% and 30%, respectively, by the third day of drying. Accordingly, a small amount of filtrate was produced only for one day and the remaining loss of moisture was achieved through evaporation. After 6 days of drying, the sludge on drying beds 1, 2 and 3 reached solids contents of 35.3%, 34% and 37.3%, respectively. By day 17, the sludge on drying beds 1, 2 and 3 reached solids contents of 74.2%, 63.4% and 64.1%, respectively. After about one month of drying, the total solids content of the sludge was 95.8%, 95% and 96% for drying beds 1, 2 and 3, respectively. The increase in solids content during the last month was very small, averaging about 1.7% for the three beds. By the end of the 2 months drying period, the total solids contents achieved were 97.4%, 97% and 97.6% for drying beds 1, 2 and 3, respectively. Regarding the bottom layers, the solids content analysed by day 17, ranged from 47% to 40%, 46.5% to 44.5% and 43.6% to 40%, for middle and bottom layers of drying beds 1, 2 and 3, respectively. By the end of the two months, the solids content ranged from 91% to 85%, 92% to 88% and 92% to 87%, for middle and bottom layers of drying beds 1, 2 and 3, respectively.

The difference between the top layers and bottom layers is not much, indicating that the air temperature and sunshine intensity had a great effect in drying even the unexposed sludge layers. Regarding the change in sludge thickness, **Figure 4.16** shows the change in sludge depth with time for the summer application. The sludge thickness decreased from 15, 20 and 25 cm, to 7, 11 and 12 cm, respectively for drying beds 1, 2 and 3, respectively, within the two months drying period.

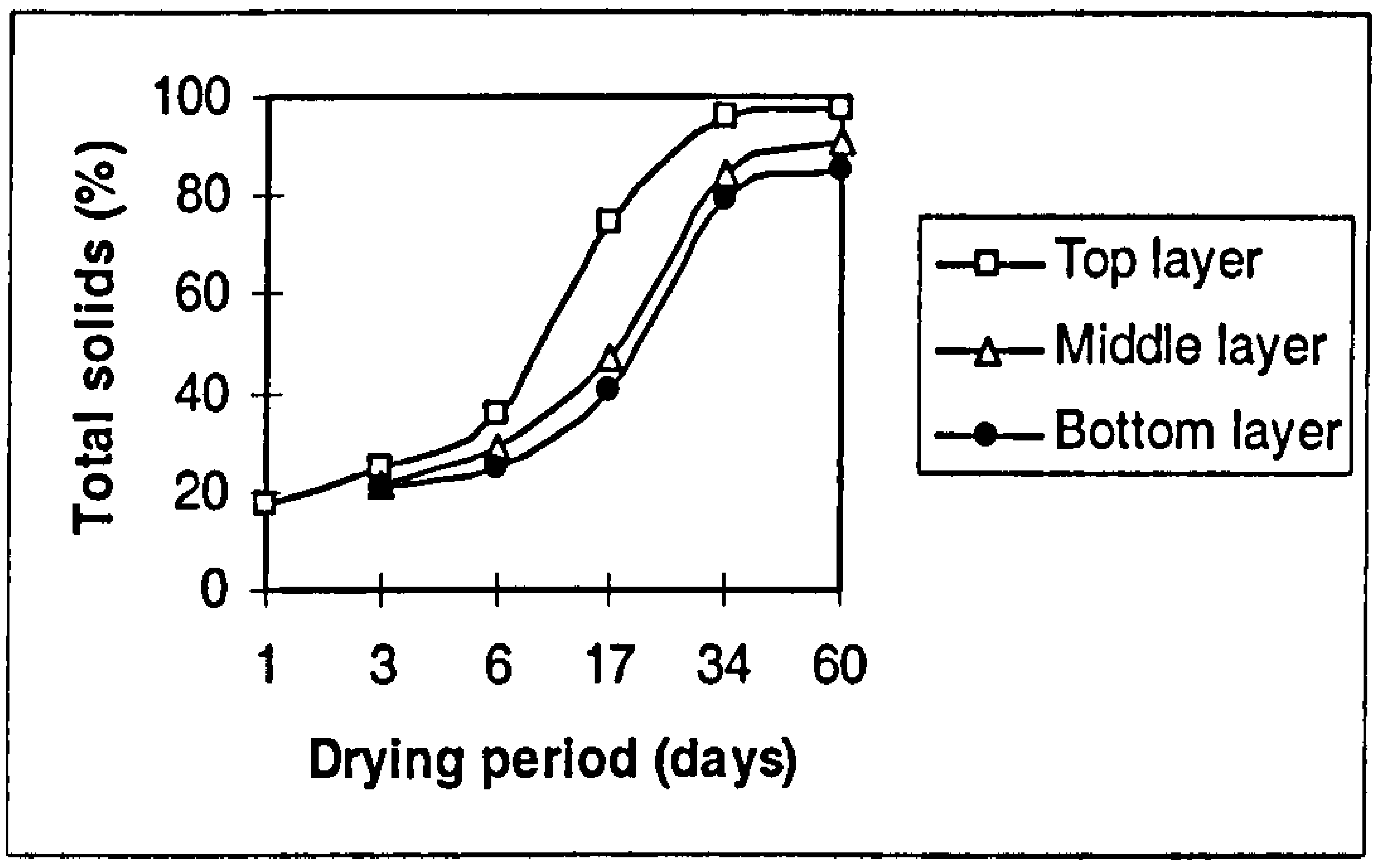

Figure 4.13. Changes in Total Solids Content with Time for Drying Bed 1 during Summer Application

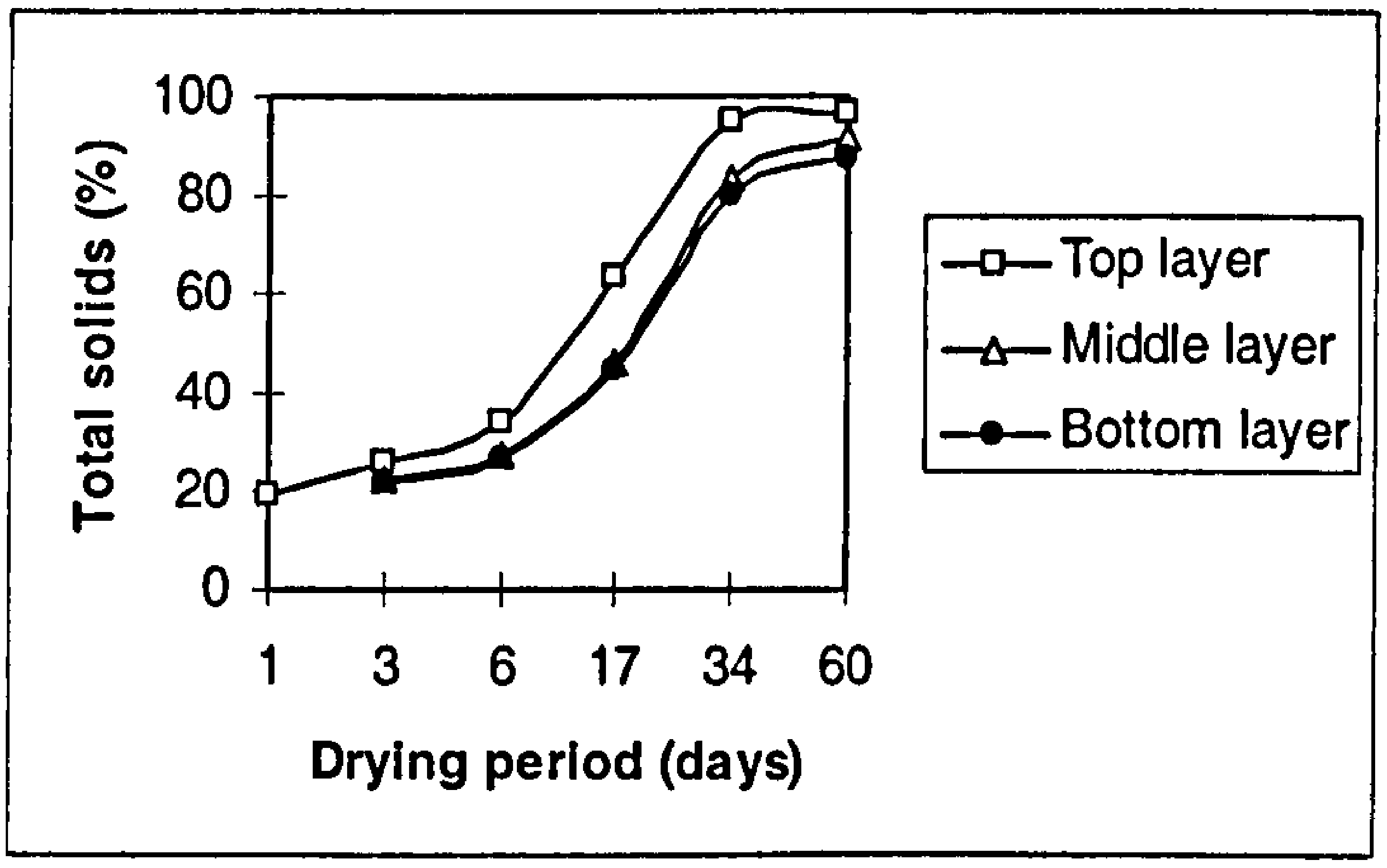

Figure 4.14. Changes in Total Solids Content with Time for Drying Bed 2 during Summer Application

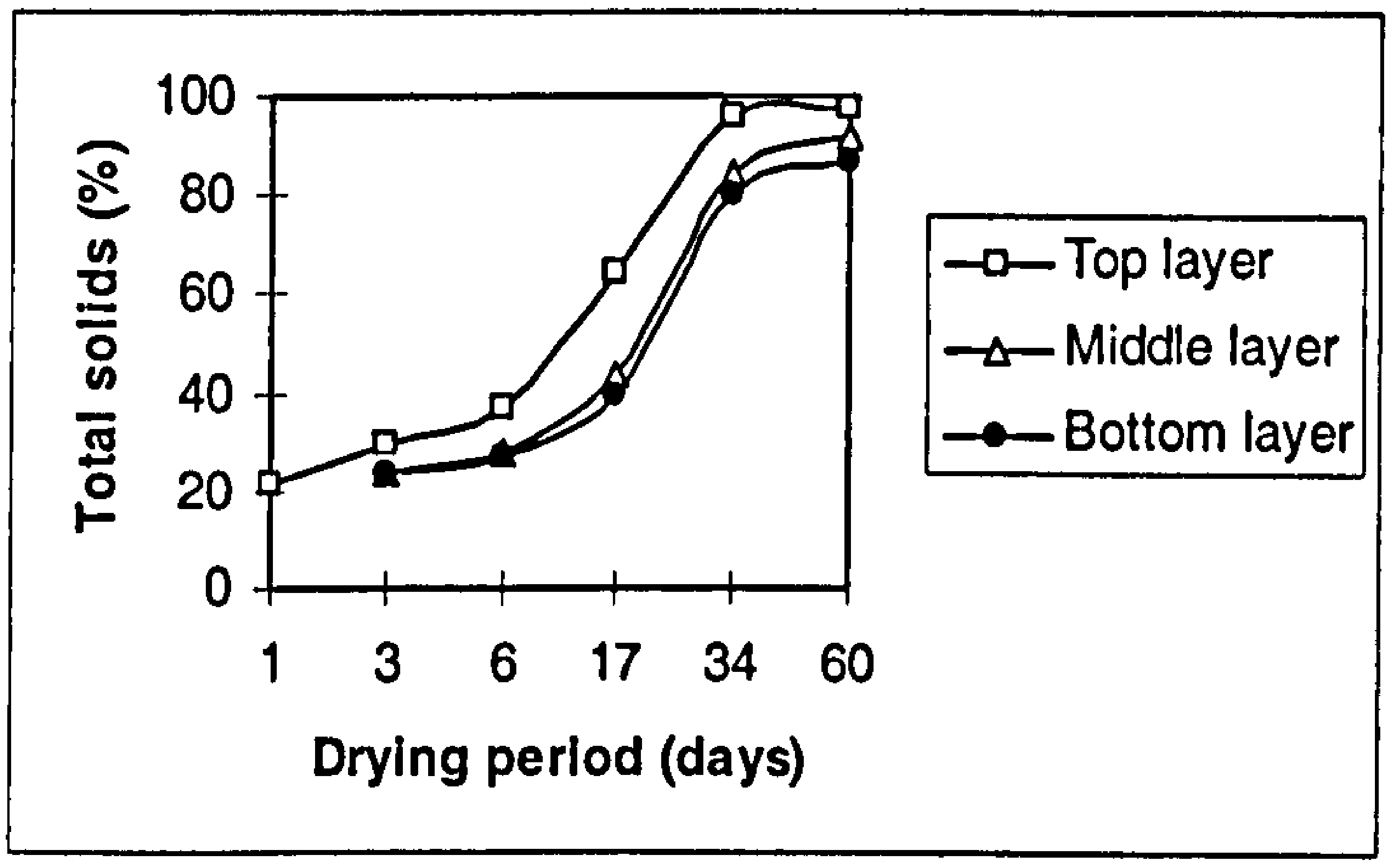

Figure 4.15. Changes in Total Solids Content with Time for Drying Bed 3 during Summer Application

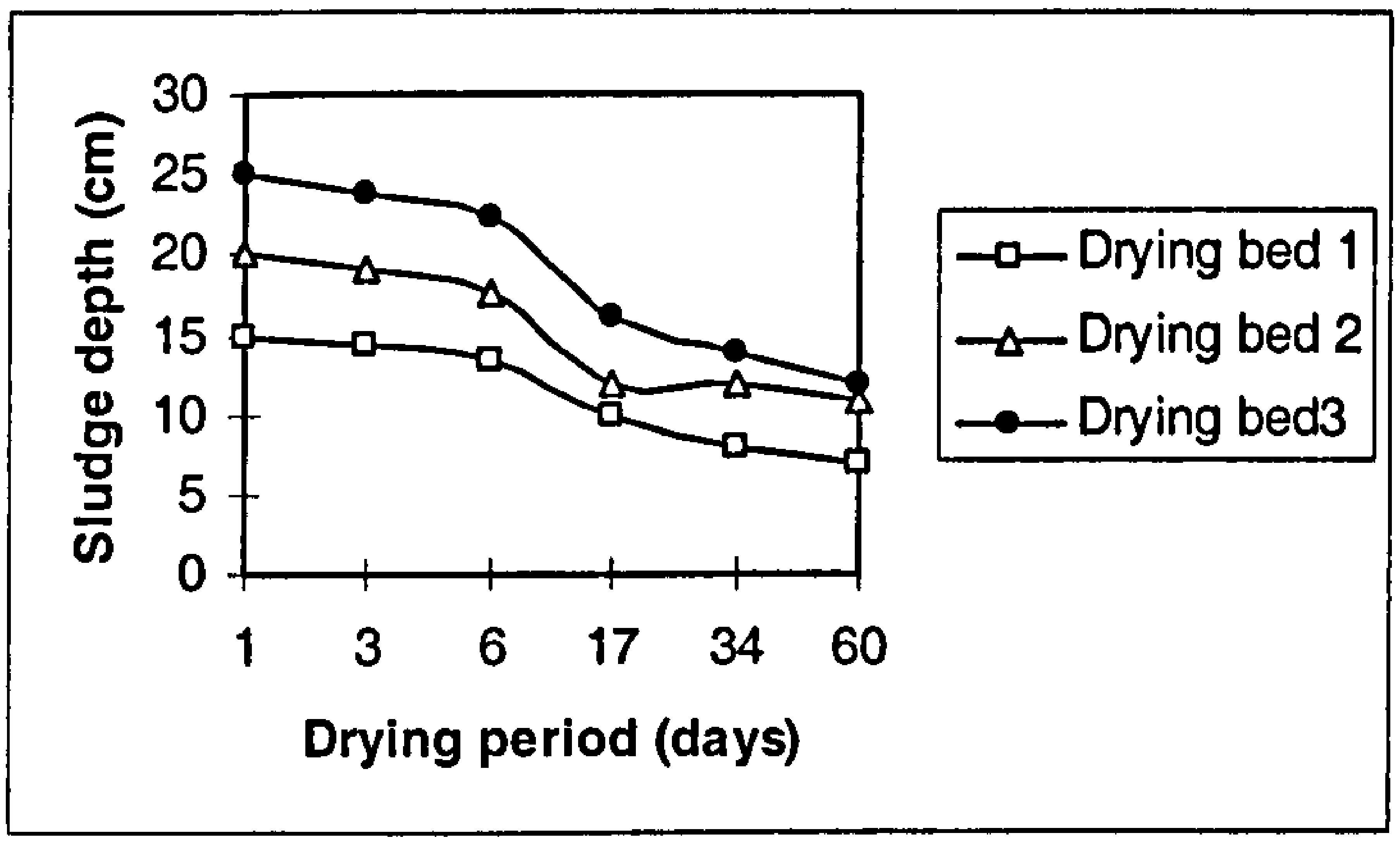

Figure 4.16. Changes in Sludge Depth with Time for Sludge applied on drying Beds during Summer Application

4.1.2.4. *Ascaris* eggs survival

As discussed in Section 4.1.1.2, from all samples collected from the anaerobic pond sludge, no viable *Ascaris* eggs were detected. Accordingly, sludge applied on the drying beds was seeded with *Ascaris vitilorum* eggs (cattle ascarid), as described in Section 3.3.1.2. After sludge was laid on the beds, the solution containing the eggs was diluted with water, applied on to the sludge, and thoroughly mixed throughout the drying beds. **Table 4.5** shows the detection and viability of *Ascaris vitilorum* eggs during the drying periods, for the winter and summer trials.

During the first application of sludge in the winter season, viable *Ascaris* eggs were detected after 18 days of drying, throughout the entire sludge layer, and for the three beds, where the solids content lay in the range of 60% to 50%. After one month of drying, no viable *Ascaris* eggs were detected in the top sludge layers of the three beds that contained an average solids content of about 85%. However, in the middle and bottom layers that contained an average solids content of about 73% and 70%, respectively, the samples examined contained viable *Ascaris* eggs. By the end of the two months drying period, the situation remained the same, no viable eggs were detected in the top sludge layers but the middle and bottom layers still showed viable *Ascaris* eggs.

Regarding the second sludge application during the winter season, it has been shown in Section 4.1.2.1 that unfavourable weather conditions were prevailing during this trial; air temperatures averaged 20°C and there was some rain. Accordingly, the solids content for the top layers remained in the range of 54% by the end of the two months drying period, as discussed in Section 4.1.2.3. These low solids content levels, accompanied by low sunshine duration and intensity, resulted in the detection of viable *Ascaris* eggs throughout the entire sludge depth on the three drying beds, throughout the drying period and until the end of the two months.

During the summer application, loss of moisture was very rapid, as shown in Section 4.1.2.3, due to the high air temperatures, sunshine intensity and duration, and no rainfall. Samples collected from the three drying beds after 17 days of drying, did not contain viable *Ascaris* eggs in the top sludge layers, which had solids content ranging from 74% to 63%. However, viable *Ascaris* eggs were detected in the middle and bottom layers of the three drying beds at day 17. After nearly one month of drying, no viable *Ascaris* eggs were detected throughout the entire sludge layers of the three drying beds, and the lowest solids content recorded was about 80% for the bottom layer of drying bed 1. These results are in agreement with previous research work carried out on *Ascaris* eggs. According to Hindiyeh (1995), 100% inactivation of *Ascaris* eggs was found at about 78% solids content, during the summer season. Remiers et al. (1986) carried out an investigation on the destruction of *Ascaris* eggs in drying beds, and found that complete destruction of *Ascaris* eggs was noted when sludge moisture content was 20%. Moreover, Feachem et al. (1983) found out that the suitable time-temperature conditions for the destruction of *Ascaris* eggs were 46°C for 1 week, or 43°C for 1 month. Such conditions were experienced during the summer trial and were successful in inactivating *Ascaris* throughout the sludge depth after nearly one month of drying. However, during winter trials, it was too wet and air temperatures were averaging 20°C, with low sunshine intensity and duration, all factors adversely affecting the loss of moisture and the destruction of *Ascaris* eggs.

From this study, as well as from previous research work, it appears that moisture is one of several variables, along with the nature of sludge (raw or digested), solar radiation, temperature and time, which can influence the destruction of *Ascaris* in drying beds. Therefore, during the summer season, *Ascaris* in sludge can be inactivated much more rapidly, compared to the winter season, as a result of the high temperatures of the sludge layers and the solar radiation intensity and duration.

Table 4.5. Detection and Viability of *Ascaris vitilorum* Eggs during Drying Periods.

Season	Application	Drying Bed	Detection of *Ascaris* Eggs during Drying Period (days)								
			18[1,2], 17[3]			32[1], 41[2], 34[3]			60		
			Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
Winter	First trial	1	+	+	+	-	+	+	-	+	+
		2	+	+	+	-	+	+	-	+	+
		3	+	+	+	-	+	+	-	+	+
	Second Trial	1	+	+	+	+	+	+	+	+	+
		2	+	+	+	+	+	+	+	+	+
		3	+	+	+	+	+	+	+	+	+
Summer		1	-	+	+	-	-	-	-	-	-
		2	-	+	+	-	-	-	-	-	-
		3	-	+	+	-	-	-	-	-	-

+: Viable eggs.

-: Non-viable eggs.

[1]: Samples collected for first trial (winter season).

[2]: Samples collected for second trial (winter season).

[3]: Samples collected for third trial (summer season).

4.1.2.5. Statistical analysis

The effects of drying period, sludge temperature, sludge depth and total solids content on the viability of *Ascaris* eggs on the drying beds were statistically analysed using binary logistic regression. MINITAB package (version 12) was used for the analysis, however, the statistical analysis led to no significant new findings.

4.2. Experimental Program II: Composting of Sewage Sludge

4.2.1. Composting of Sewage Sludge, Agricultural Wastes & Cement Dust in Different Proportions Using Passive Technology

4.2.1.1. Temperature trends & variations

Temperature is a very good indicator of microbial activity and the decomposition rate of organic matter during composting. Changes in the temperature within each pile were recorded during the composting period. The ambient temperature variations throughout the composting period (mid May to end of September 1999) averaged between 48 and 28°C during daytime and 29 to 17°C at night. **Appendix 4.2** shows the data collected on the piles during the composting period, including pile temperatures and CO_2 readings.

Generally, the composting process for all piles in phases 1 and 2 exhibited the classical temperature pattern, where it is possible to distinguish the mesophilic, thermophilic and cooling down (maturation) phases. However, the difference between the piles was mainly the temperature levels. The windrow and passive piles showed a longer mesophilic phase (1 day), compared to several hours for the piles containing sludge, bulking agent and cement dust. This occurred due to the conversion of CaO to $Ca(OH)_2$ when the cement dust was added to the mixture. An exothermic reaction occurred, which released heat, and accordingly the temperature within the pile increased almost immediately. The passive technology was very successful in naturally controlling the internal temperatures within the piles (not exceeding 73°C), even with the high cement concentrations (40% and 50% cement dust).

Phase 1 piles were turned twice during the composting period. The first turn was during the fermentation phase, after 26 days of composting, and this was due to the remarkable decrease in the microorganisms' activity (indicated by low temperatures and CO_2 evolution within the piles). The second turn was at the start of the maturation phase, after about 2 months of composting, when the ventilation pipes were removed. During phase 2, the piles were turned once only, at the start of the maturation phase (after about 2 months of composting). For all piles, it was noticed that after turning the temperature elevated for a certain period of time, indicating that the fermentation process was still proceeding and that part of the organic matter had not yet been digested. In general, the continuous decline in temperature can be attributed to the exhaustion of available substrate, especially since the passive technology did not involve regular turning of piles. However, this does not mean that the organic matter was completely digested since not all the material is directly available to the microflora. Therefore, during the fermentation process, one turn was very beneficial in exposing undigested organic matter to the microflora.

Figures 4.17 & 4.18 show the temperature trends for the windrow and passive piles, respectively. The mesophilic stage lasted for about one day, after which the thermophilic stage started with temperatures increasing rapidly, reaching 60 to 72°C for about 24 days in the windrows and 60 to 71°C for about 34 days in the passive piles. Thereafter, a continuous decline of temperature was observed, until the end of the fermentation phase when the temperature ranged from about 45 to 60°C and from 50 to 58°C for the windrow and passive piles, respectively. During the maturation phase, the temperature decreased smoothly from 62 to 37°C and from 61 to 37°C for the windrow and passive piles, respectively. By comparing both piles, it is evident that the passive pile maintained regular high temperature for a longer duration (34 days) compared to the windrow pile. This was mainly due to the favourable aerobic conditions within the pile.

Figures 4.19 & 4.20 show the temperature trends for the 30% & 40% cement dust piles, respectively. The mesophilic stage lasted for about 2 hours, after which temperatures increased to more than 50°C. Temperatures reached 53 to 70°C and 55 to 71°C for about 26 days, for the 30% & 40% cement dust piles, respectively. Thereafter, a continuous decline of temperature was observed, until the end of the fermentation phase when the temperature ranged from about 44 to 68°C and from 50 to 73°C for the 30% & 40% cement dust piles, respectively. During the maturation phase, temperature decreased from 55 to 35°C and from 58 to 32°C for the 30% & 40% cement dust piles, respectively.

Phase 2 piles also showed the typical temperature trend, with rapid transition from the mesophilic into the thermophilic stage and finally to the maturation stage, where the pile temperature reach ambient air temperature (30°C range). **Figures 4.21 & 4.22** show the result of the 10% & 20% cement dust piles, respectively. The mesophilic stage lasted for several hours, after which temperatures increased to more than 50°C. Temperature increased rapidly reaching 50 to 73°C and 50 to 68°C during the fermentation stage for the 10% & 20% cement dust piles, respectively. At the start of the maturation phase, the piles were turned and their temperature increased for several days, after which temperatures decreased smoothly from 64 to 33°C and from 64 to 36°C for the 10% & 20% cement dust piles, respectively.

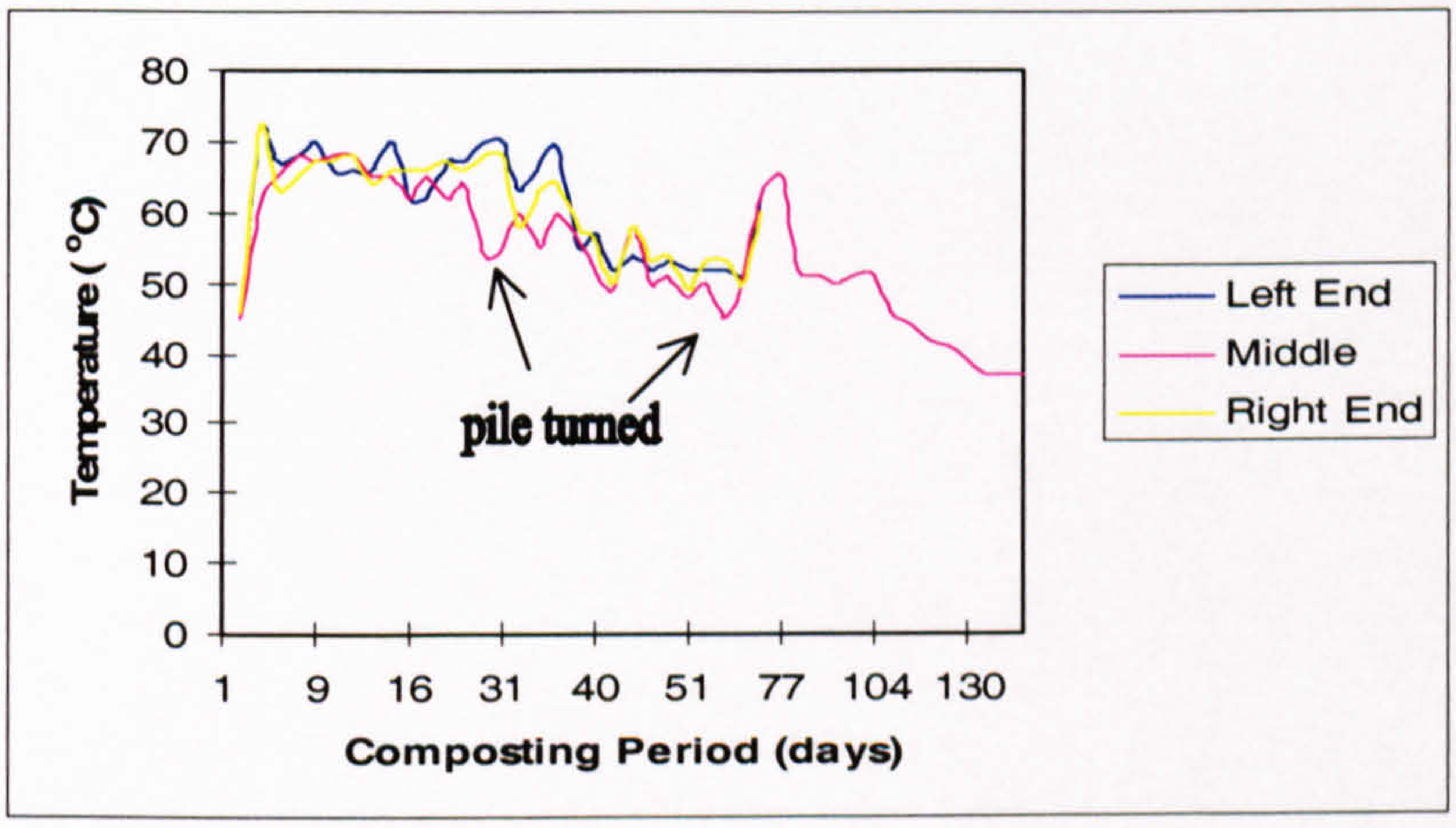

Figure 4.17. Temperature Trend for the Windrow Pile, Phase 1

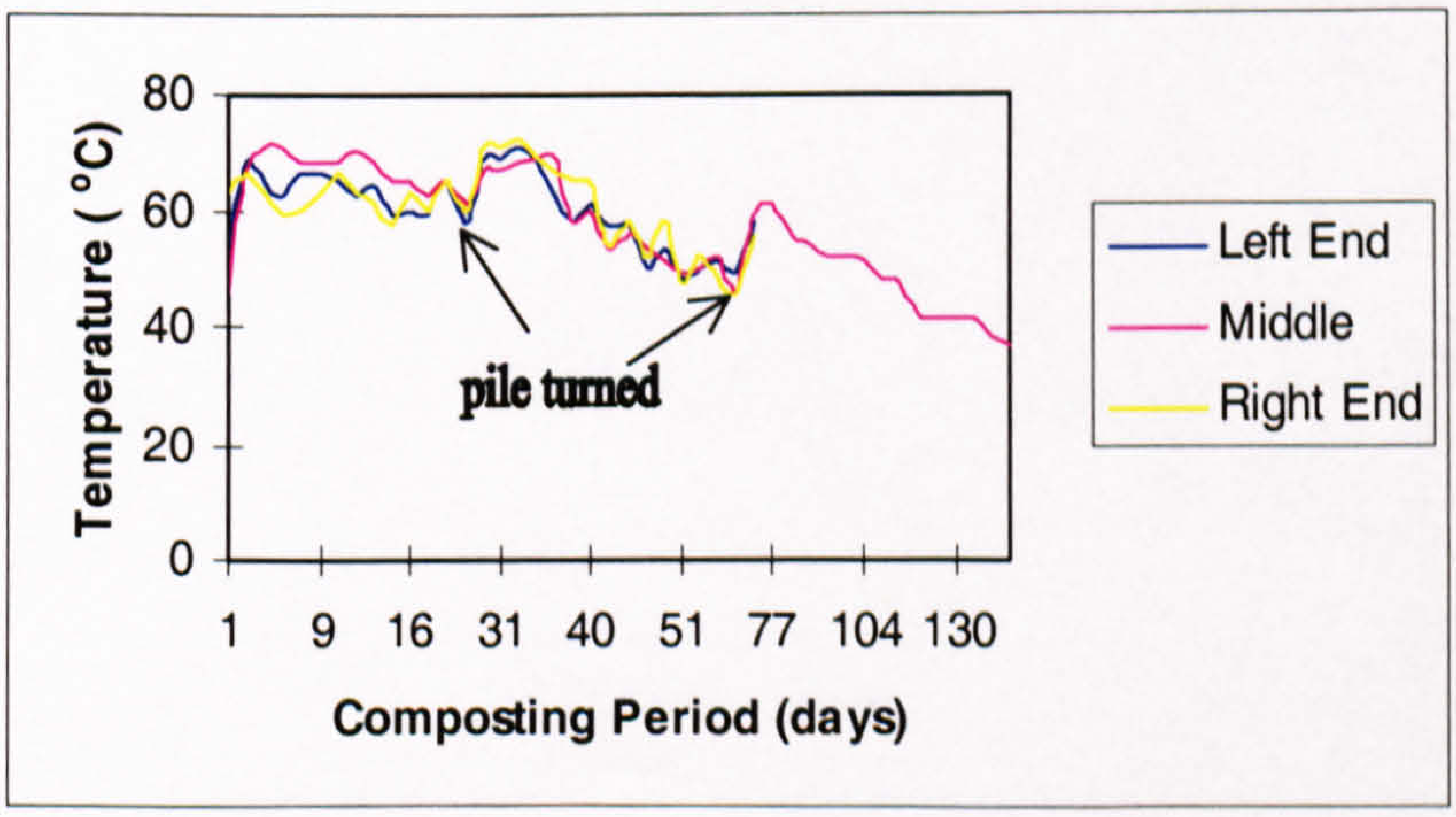

Figure 4.18. Temperature Trend for the Passive Pile, Phase 1

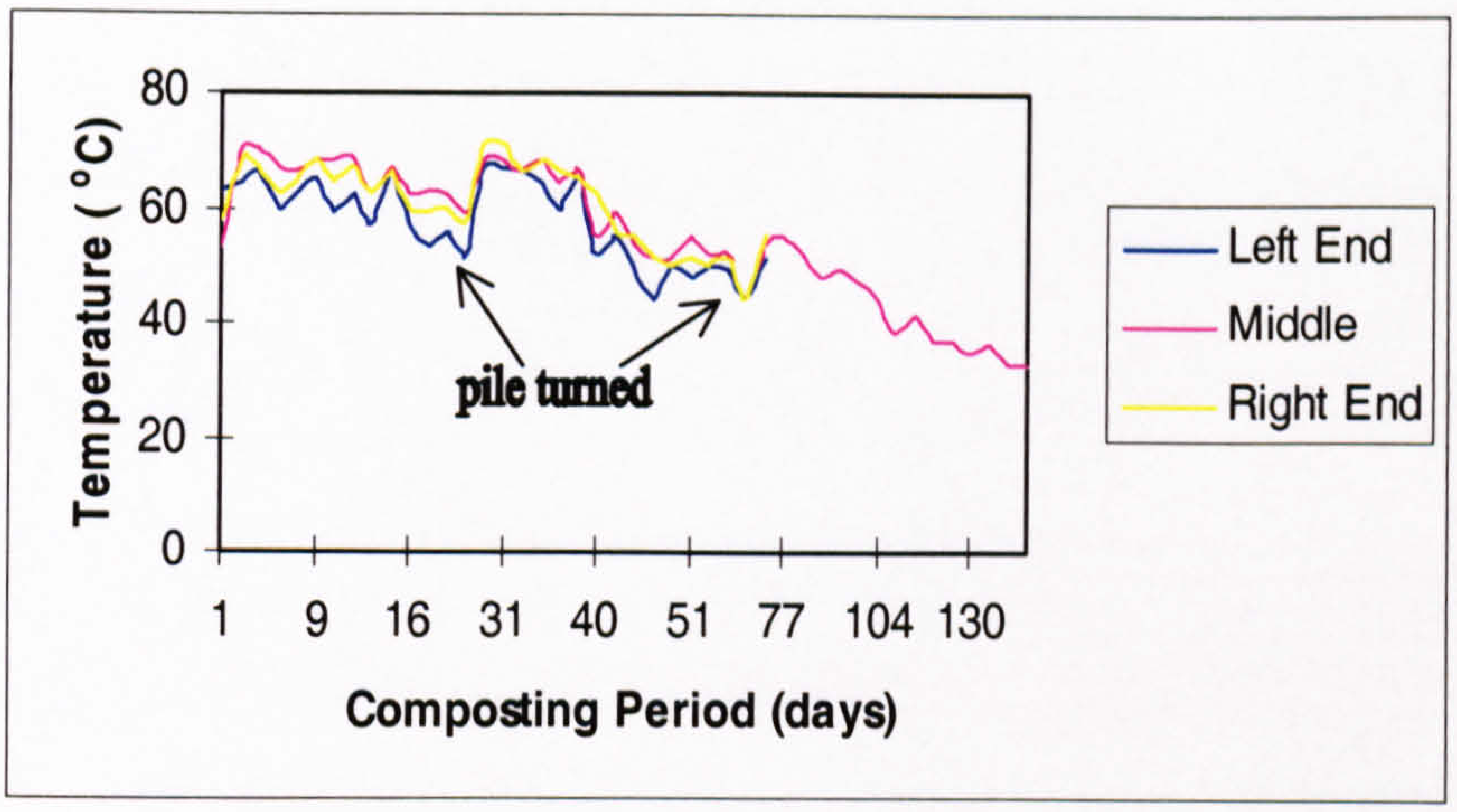

Figure 4.19. Temperature Trend for 30% Cement Dust Pile, Phase 1

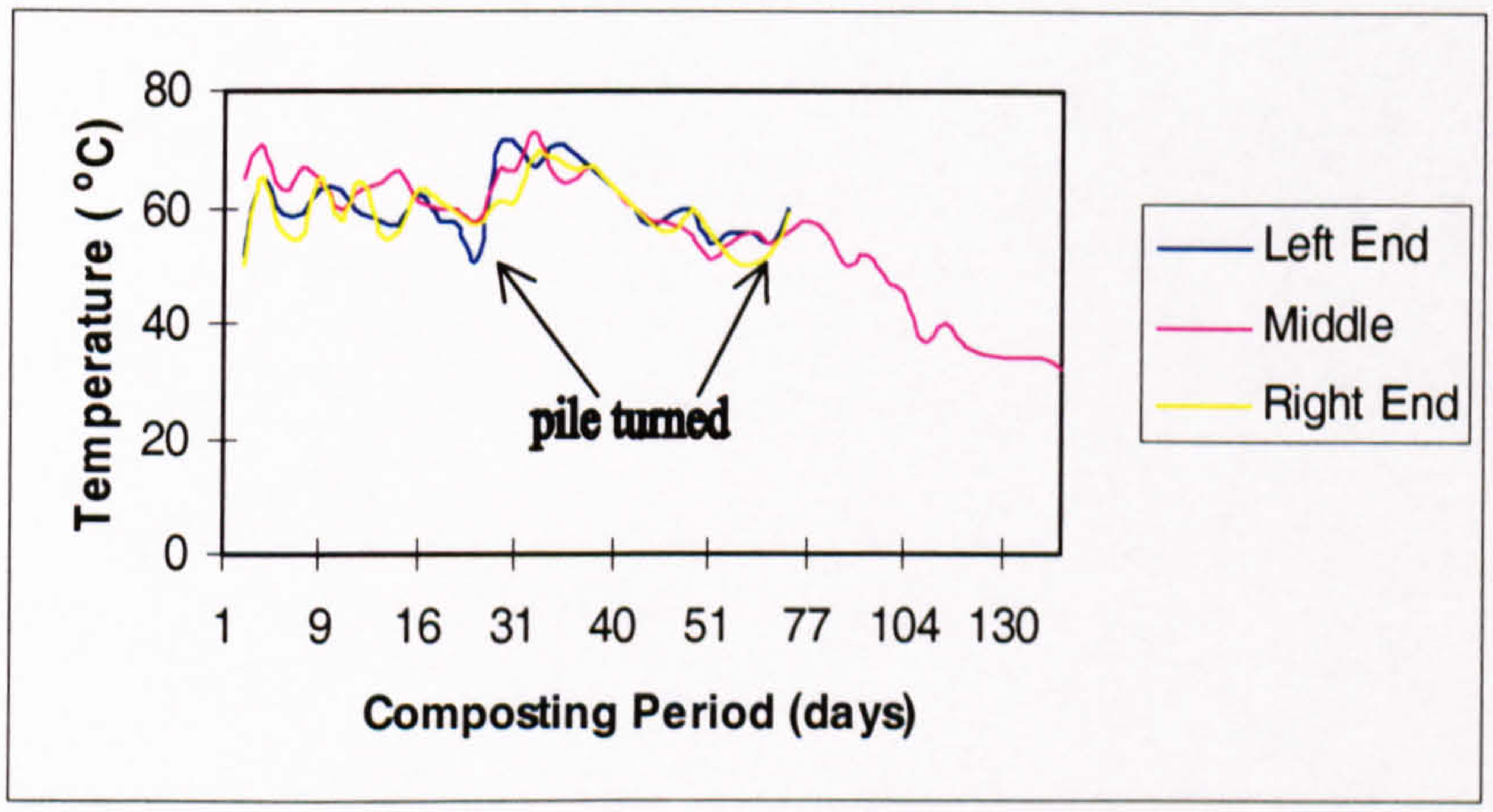

Figure 4.20. Temperature Trend for 40% Cement Dust Pile, Phase 1

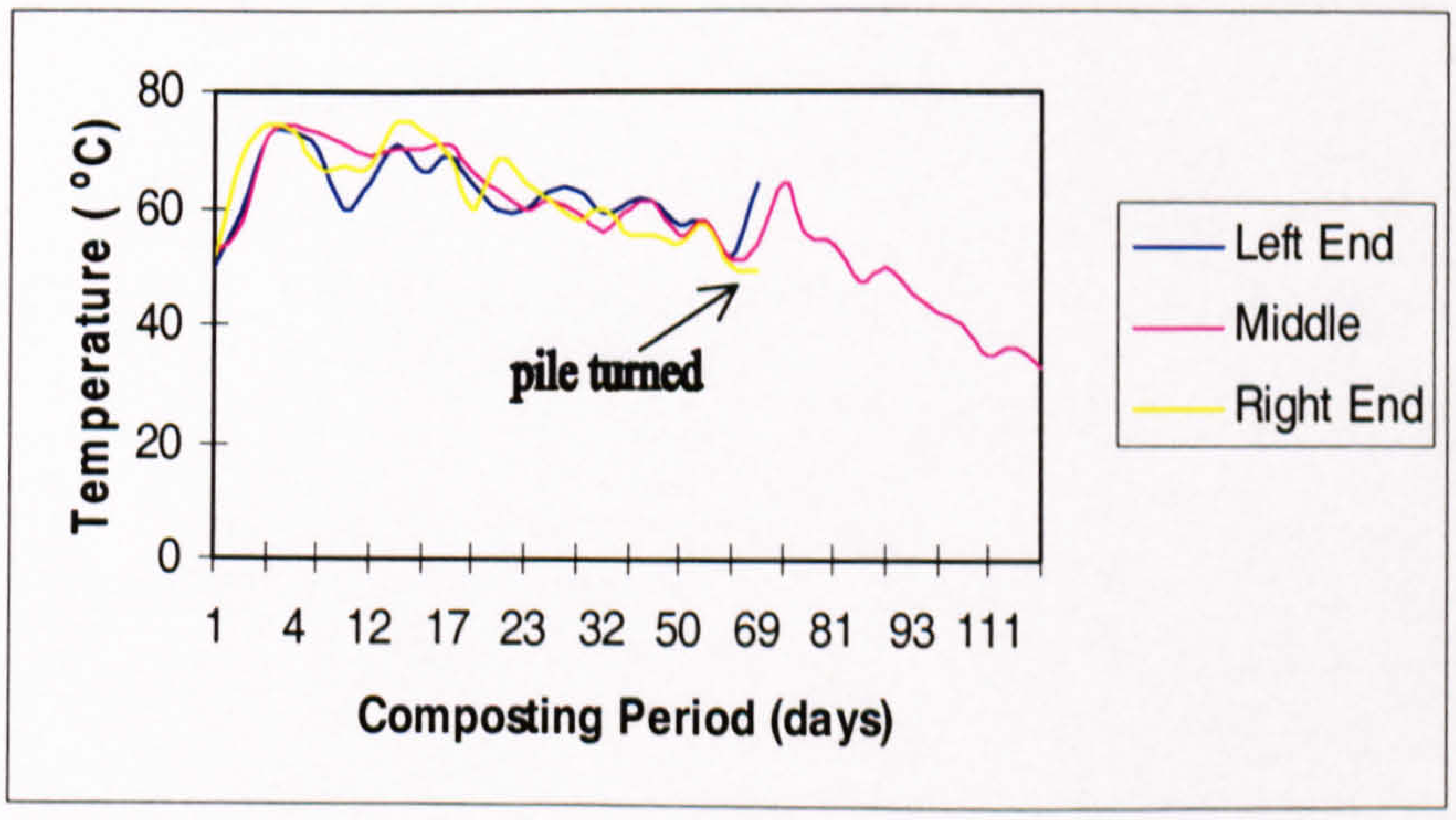

Figure 4.21. Temperature Trend for 10% Cement Dust Pile, Phase 2

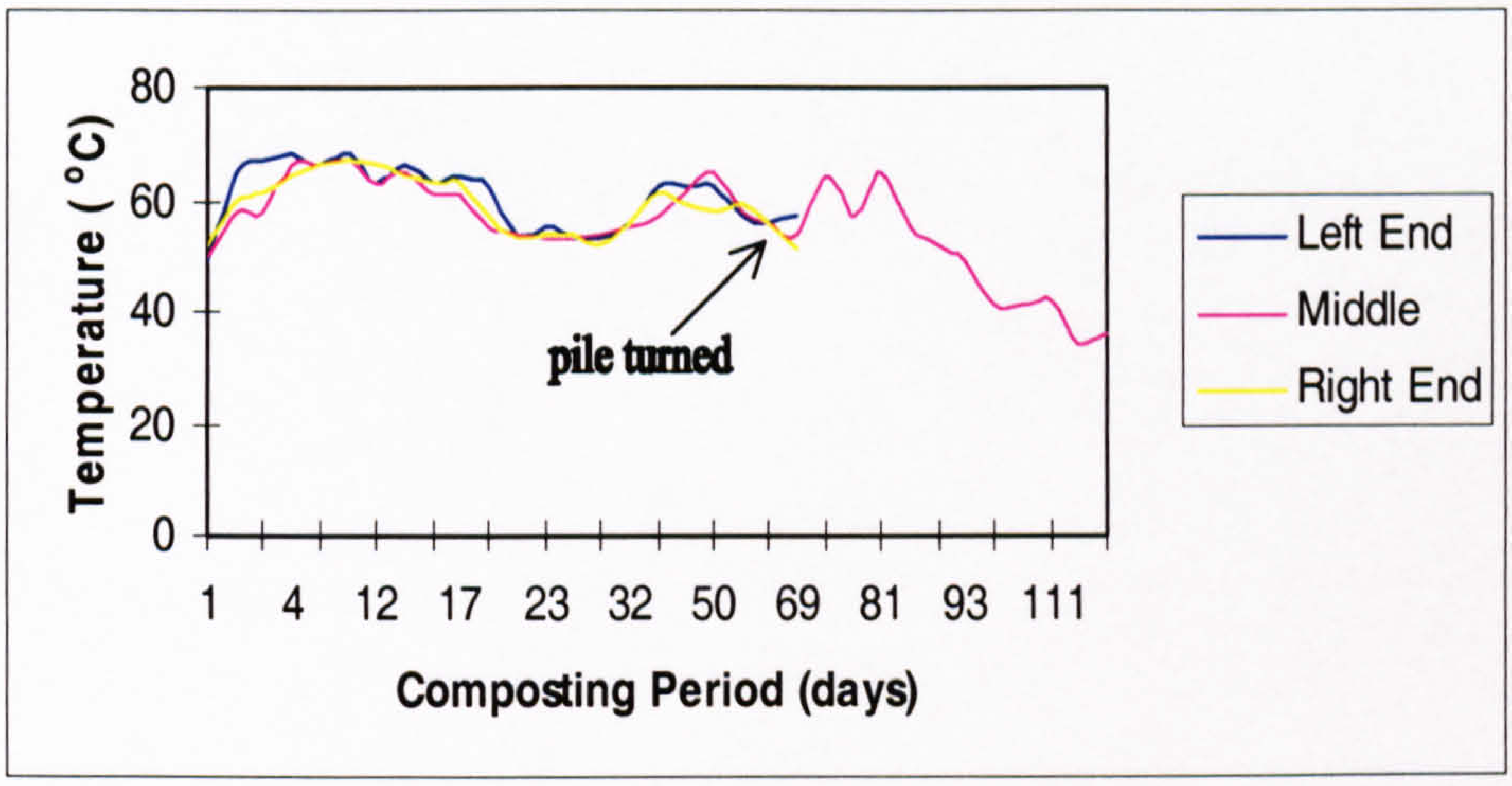

Figure 4.22. Temperature Trend for 20% Cement Dust Pile, Phase 2

Figures 4.23 & 4.24 show the results for the 25% & 35% cement dust piles, respectively. The mesophilic stage lasted for several hours, as in case of the other cement dust piles, after which temperature increased to more than 52°C. The pile temperature increased from 51 to 71°C in 54 days, and 52 to 71°C in 50 days for the 25% & 35% cement dust piles respectively. At the start of the maturation phase, temperatures increased for several days as a result of the turning of the piles, after which temperatures decreased from 61 to 36°C and from 66 to 33°C for the 25% & 35% cement dust piles, respectively.

Figures 4.25 & 4.26 show the results for the 50% cement dust & 30% cement dust (without bulking agent) piles, respectively. The mesophilic stage lasted for several hours for the 50% pile, whereas the 30% cement dust pile (without bulking agent) stayed below 45°C for about 6 days. Temperature increased to 52 to 71°C for 50 days, and 55 to 68°C for 57 days for the 50% cement dust & 30% cement dust (without bulking agent) piles, respectively. At the start of the maturation phase, temperature increased for several days as a result of the turning of the piles, after which temperature decreased from 56 to 37°C and from 66 to 35°C for the 50% cement dust & 30% cement dust (without bulking agent) piles, respectively. The 30% cement dust pile (without bulking agent) exhibited a delay in the fermentation process mainly due to the prevailing anaerobic conditions. No pore spaces were present and, accordingly, the fermentation process started after the moisture content decreased to an acceptable level, providing air paths through the pile. The passive technology and the presence of the ventilation pipes beneath the pile enhanced the flow of air and introduced aerobic conditions for the microflora to start decomposing the waste.

It is important to note at this stage that, due to the moisture absorbing effect of the cement dust, the high temperatures attained for long periods of time and high pH, resulted in unfavourable conditions for the microflora in breaking down the organic matter.

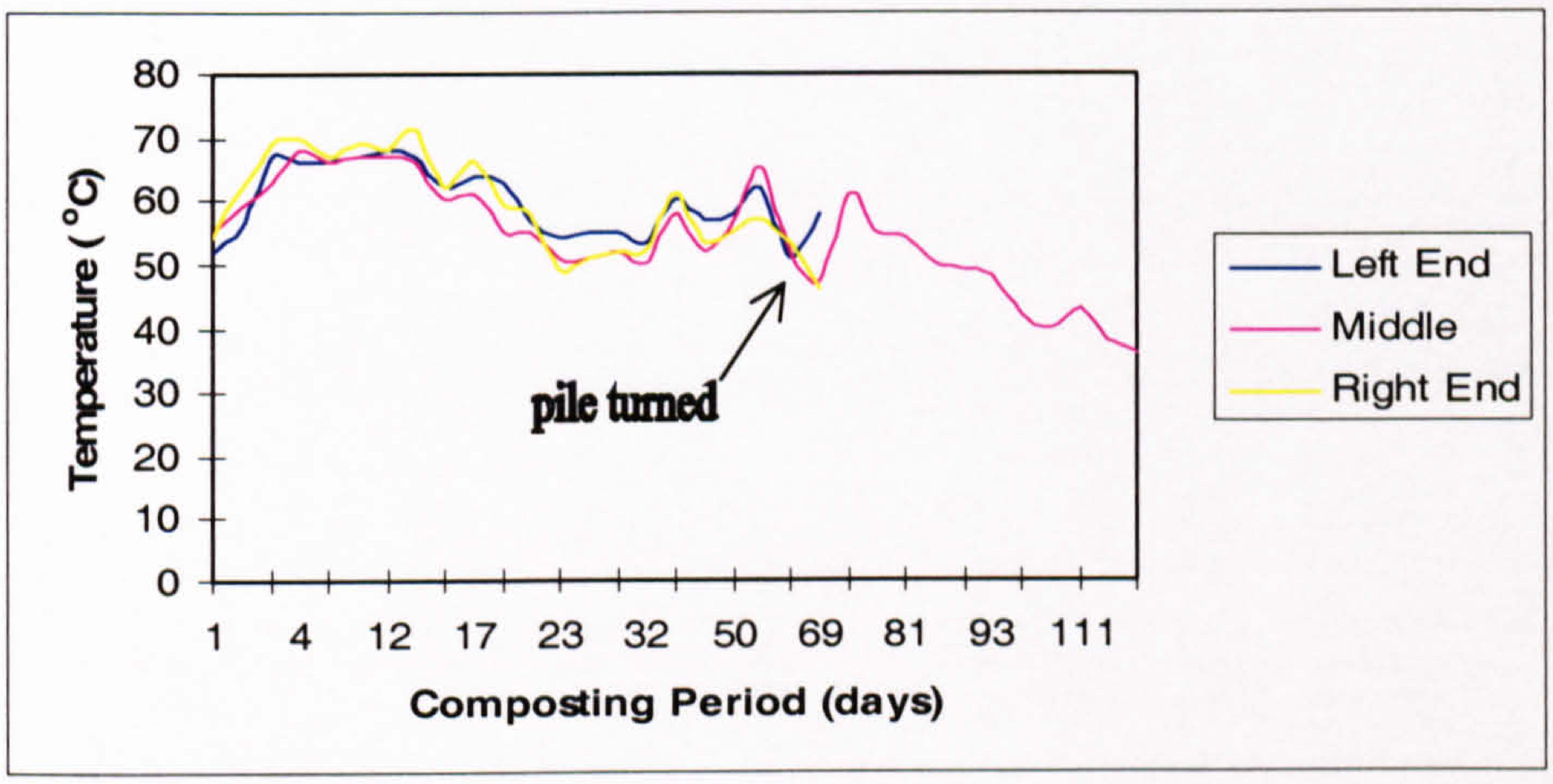

Figure 4.23. Temperature Trend for the 25% Cement Dust Pile, Phase 2

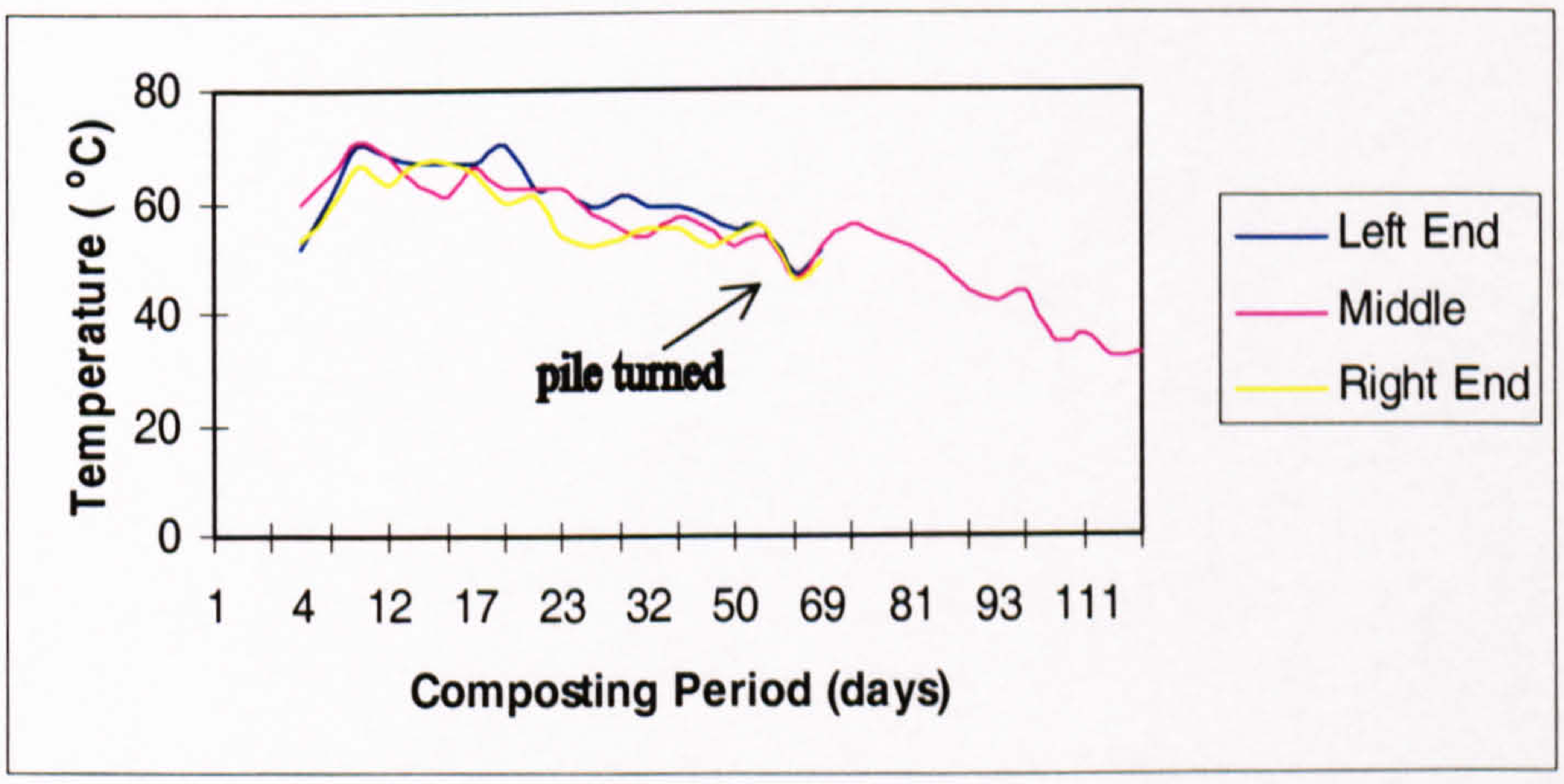

Figure 4.24. Temperature Trend for the 35% Cement Dust Pile, Phase 2

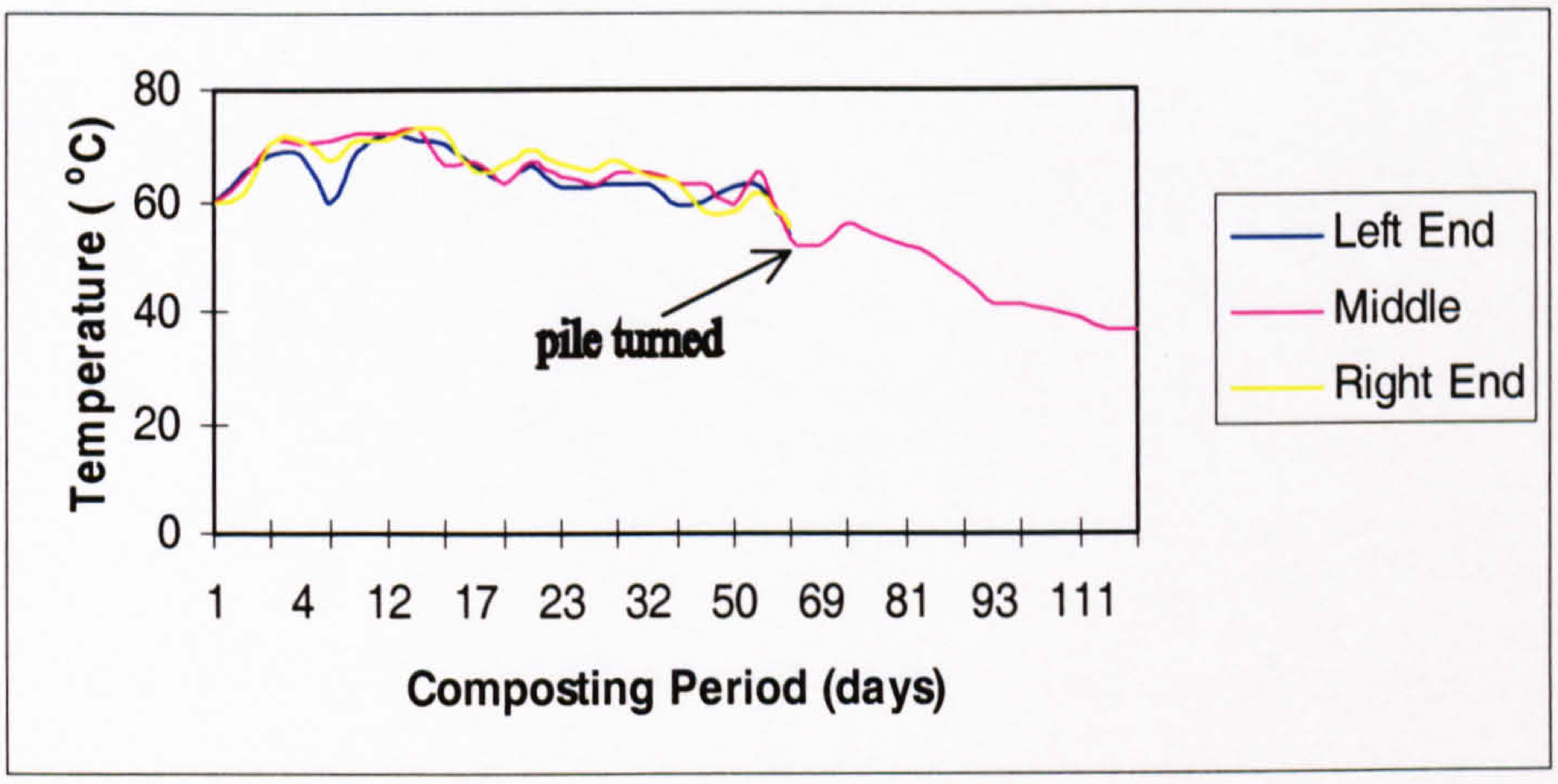

Figure 4.25. Temperature Trend for the 50% Cement Dust Pile, Phase 2

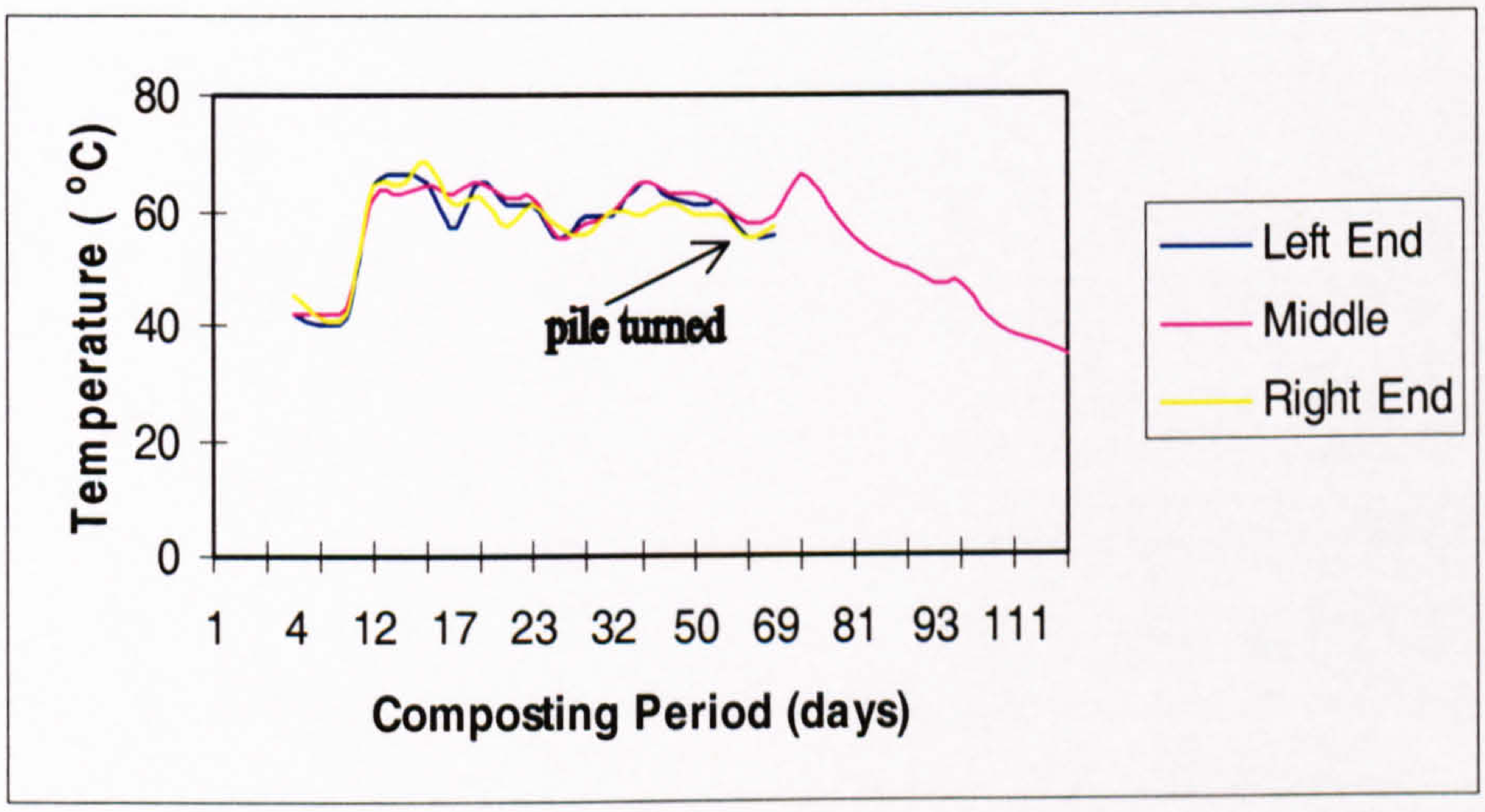

Figure 4.26. Temperature Trend for the 30% Cement Dust Pile without Bulking Agent, Phase 2

4.2.1.2. CO_2 evolution & O_2 depletion

In addition to using heat output as a measure of composting activity, respiration measurements were used as indicators of composting action. Generally, aerobic composting consumes large amounts of oxygen. During the first days of the composting process, the readily degradable components of the raw materials are readily available for the microflora to digest and are rapidly metabolized. Oxygen depletion and carbon dioxide evolution are direct indicators that the fermentation

process is taking place and that the aerobic bacteria are consuming the oxygen in digesting the organic matter, with the release of CO_2, water vapour and heat.
Due to the exothermic effect of cement kiln dust addition to the mixture, CO_2 evolution would be a more useful measure of the composting activity and the decomposition process, rather than the temperature effect. As long as the organic matter is being consumed, CO_2 is released. On the other hand, an increase in temperature within the cement dust piles does not ensure that the decomposition process is ongoing. Accordingly, in the case of the cement dust piles, the CO_2 evolution would be a much more useful measure of the composting process.

Air contains about 20% oxygen and, according to Rynk (1992), a minimum oxygen concentration of 5% within the pore spaces should be maintained for aerobic conditions. The relationship between oxygen and carbon dioxide percentage could be expressed as follows:

$$O_2\,\% = 20\% - CO_2\,\%$$

Accordingly, CO_2 evolution percentage levels within the piles were monitored throughout the composting period (fermentation and maturation stages) for phases 1 and 2. For all the piles it was noted that, after turning, CO_2 percent increased for a certain period of time, indicating that the fermentation process was ongoing and that part of the organic matter was yet to be digested. However, at the start of the maturation stage and after turning of piles, as the microflora came into contact with the remaining organic matter, under favourable composting conditions, breakdown of the organic matter was proceeding, although less rapidly.

Generally, the CO_2 evolution percentage and oxygen consumption levels for the piles without cement dust (windrow and passive piles) were normal. However, for the piles containing cement dust, microbial breakdown and digestion of the organic matter was delayed and prolongation of the time for start up of the digestion process was clear. This was mainly due to both the high temperature and pH levels attained. Moreover, although the piles were mixed thoroughly, in order to form as homogenous a pile as possible, still some of the CO_2 percentage levels were inconsistent and varied from one day to the next. This mainly depended on the sampling location; at certain places within the pile favourable conditions were prevailing while in other locations unfavourable conditions existed. This affected the degree of degradation of organic matter and, accordingly, the temperature levels and CO_2 levels.

Figures 4.27 & 4.28 show the CO_2 percentage levels for the windrow and passive piles, respectively. For the windrow pile, high CO_2 percentage levels were reached, averaging between 7% and 16%. After the first turn, CO_2 increased rapidly, reaching 16% and thereafter decreased, to reach 4% at the end of the fermentation stage. However, at certain locations in the piles oxygen was very limited and anaerobic conditions prevailed, which is to be expected. During the maturation phase, bacteria were still digesting the organic matter, but at a lower rate. The CO_2 percentage levels ranged between 10% and 4%, at the end of the composting period.

For the passive pile, CO_2 percentage levels were averaging between 1% and 12% and, after the first turn, reaching 12%. Thereafter, the CO_2 level decreased to 0% at the end of the fermentation stage. This indicates that the passive technology was efficient in supplying sufficient oxygen through the ventilation pipes and upwards within the pile. However, the 0% CO_2 was as to be expected as a result of the non turning of the pile and the microflora not getting into contact with undigested organic matter. During the maturation phase, bacteria were still digesting the organic matter but at a lower rate. CO_2 ranged between 10% and 4% at the end of the composting period, which indicates that some of the organic matter was not yet broken down.

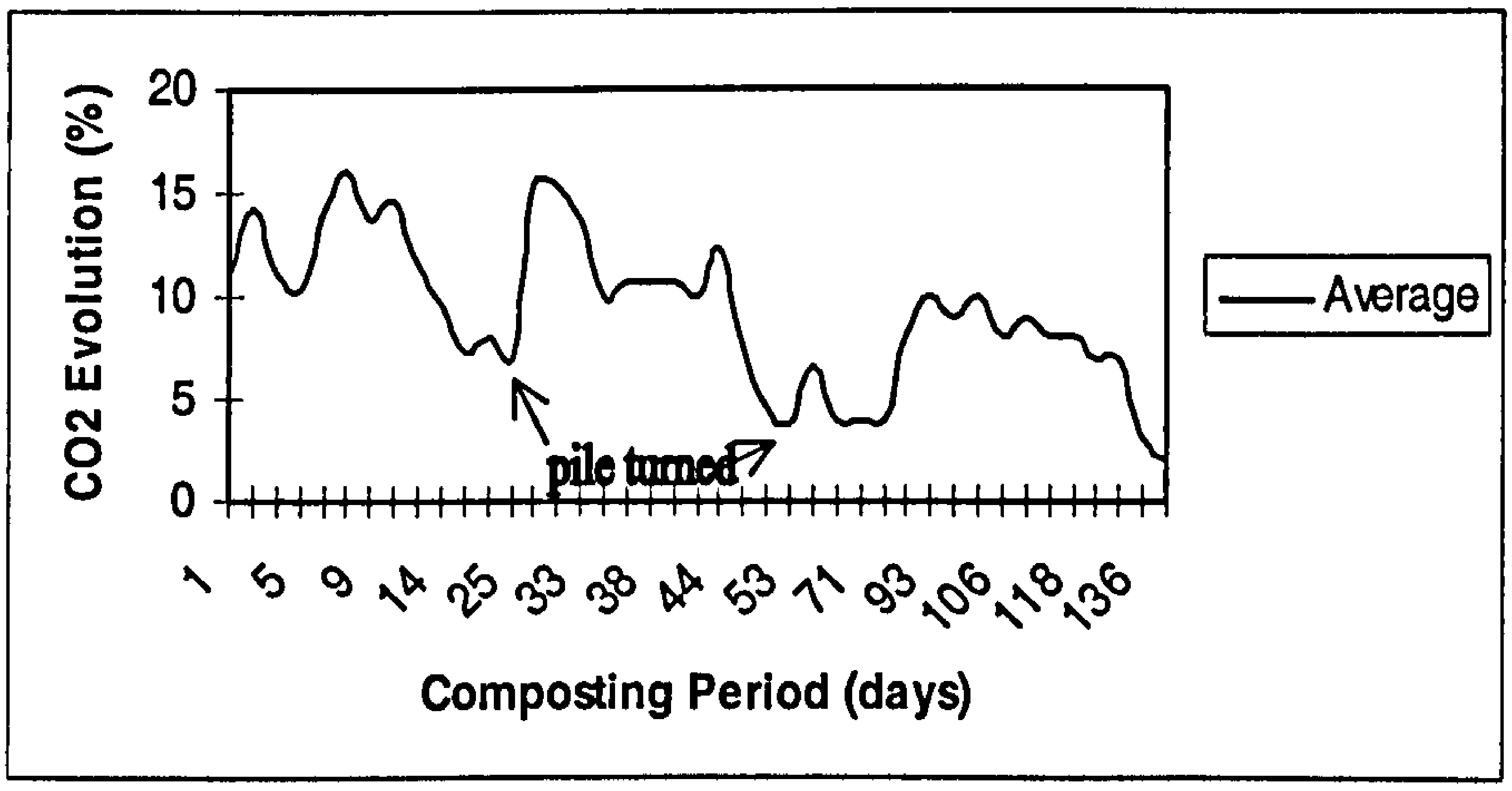

Figure 4.27. CO_2 **Evolution within the Windrow Pile, Phase1**

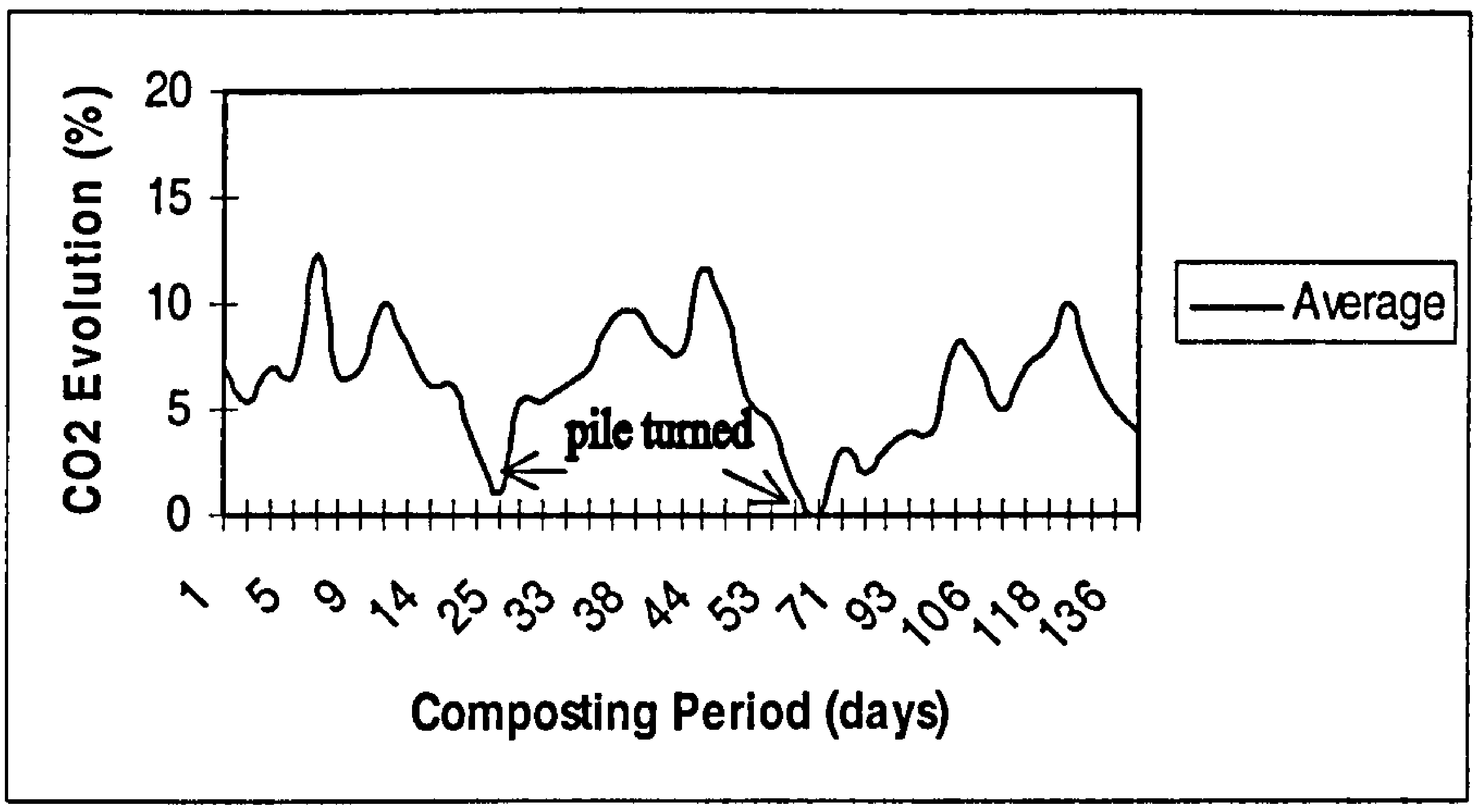

Figure 4.28. CO_2 Evolution within the Passive Pile, Phase 1

Figures 4.29 & 4.30 show the CO_2 percentage levels for the 30% and 40% cement dust piles, respectively. For the 30% cement dust pile, 1% to 8% CO_2 levels were reached and, after the first turn, CO_2 increased gradually from 2% to 11%, decreasing again to 0% at the end of the fermentation stage. At the start of the maturation phase, the piles were very well turned and the build-up of the microflora was progressing. In addition, the bacteria were in contact with the organic matter and, accordingly, CO_2 started to increase rapidly, from 0% at the end of the fermentation phase to 7% reaching a peak of 11% before starting to slow down to 3%.

For the 40% cement dust pile, there was little bacterial activity and hence little degradation of organic matter had taken place during the fermentation process, even after the pile was turned thoroughly. The CO_2 levels fluctuated between 0% and 2%. However, after two months of fermentation and at the start of the maturation phase, there was a build-up of microflora, and the digestion process started rapidly, raising the CO_2 levels to a peak of 9% thereafter decreasing to 2%. This indicates that the 40% cement dust concentration had a negative initial effect on the activity of the microflora due to the high pH and high temperature levels attained, as well as the dehydration effect. Only after about 10 weeks of composting did the bacterial activity start again, as the pH levels decreased to about 8.5, giving more favourable conditions than the earlier pH of 11.5.

Figures 4.31 & 4.32 show the CO_2 percentage levels for the 10% and 20% cement dust piles of phase 2, respectively. For the 10% cement dust pile, CO_2 levels started to increase from the first day of composting averaging 6%, with maximum increase of 9%, and thereafter constantly decreased to reach 2% at the end of the fermentation stage. During the maturation stage and after turning, the CO_2 percentage ranged between 11% and finally reached 1% at the end of the composting period.

For the 20% cement dust pile, bacterial activity started from the second day of composting and the CO_2 percentage increased from 7% to 12%, thereafter decreasing to 2% by the end of the fermentation stage. During the maturation stage, CO_2 levels increased rapidly to 9% and by the end of the maturation stage decreased to 3%. In general, the 10% and 20% concentration of cement dust performed well, and the fermentation process started rapidly. The microflora digested the waste without any hindrance to the composting process.

Figures 4.33 & 4.34 show the CO_2 trend for the 25% and 35% cement dust piles of phase 2, respectively. For the 25% cement dust pile, CO_2 levels started to increase from first day of composting, averaging 2%, with maximum increase of 13%, and thereafter decreased to reach 4% at the end of the fermentation stage. During the maturation stage and after turning, the CO_2 percentage ranged between 11% and 1% by the end of the composting period.

For the 35% cement dust pile, bacterial activity started after four days of composting, and average CO_2 percentage ranged from 13% to 3% at the end of the fermentation stage. During the maturation stage, CO_2 levels increased and ranged from 12% to 2% by the end of the composting period.

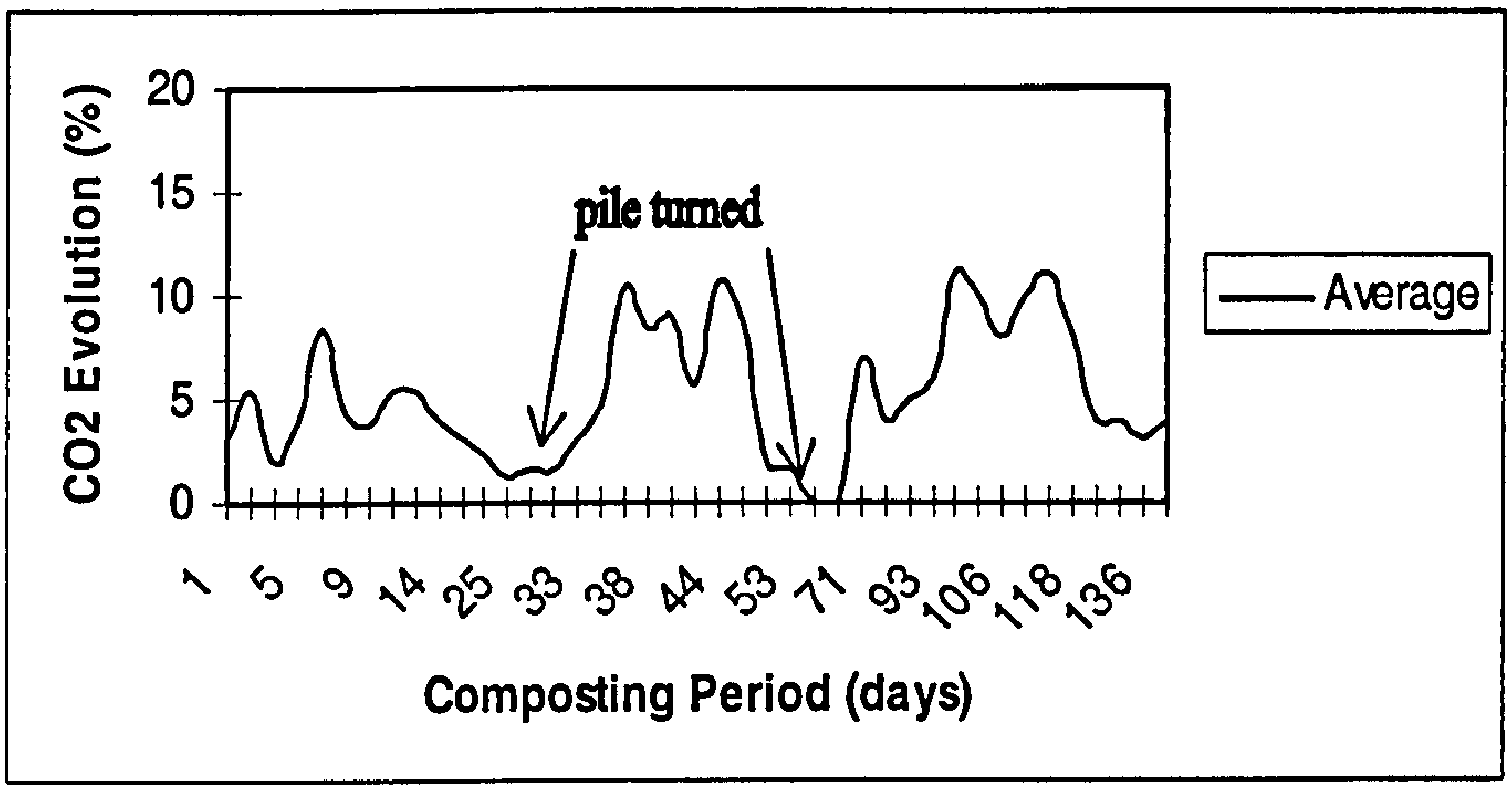

Figure 4.29. CO$_2$ Evolution within the 30% Cement Dust Pile, Phase 1

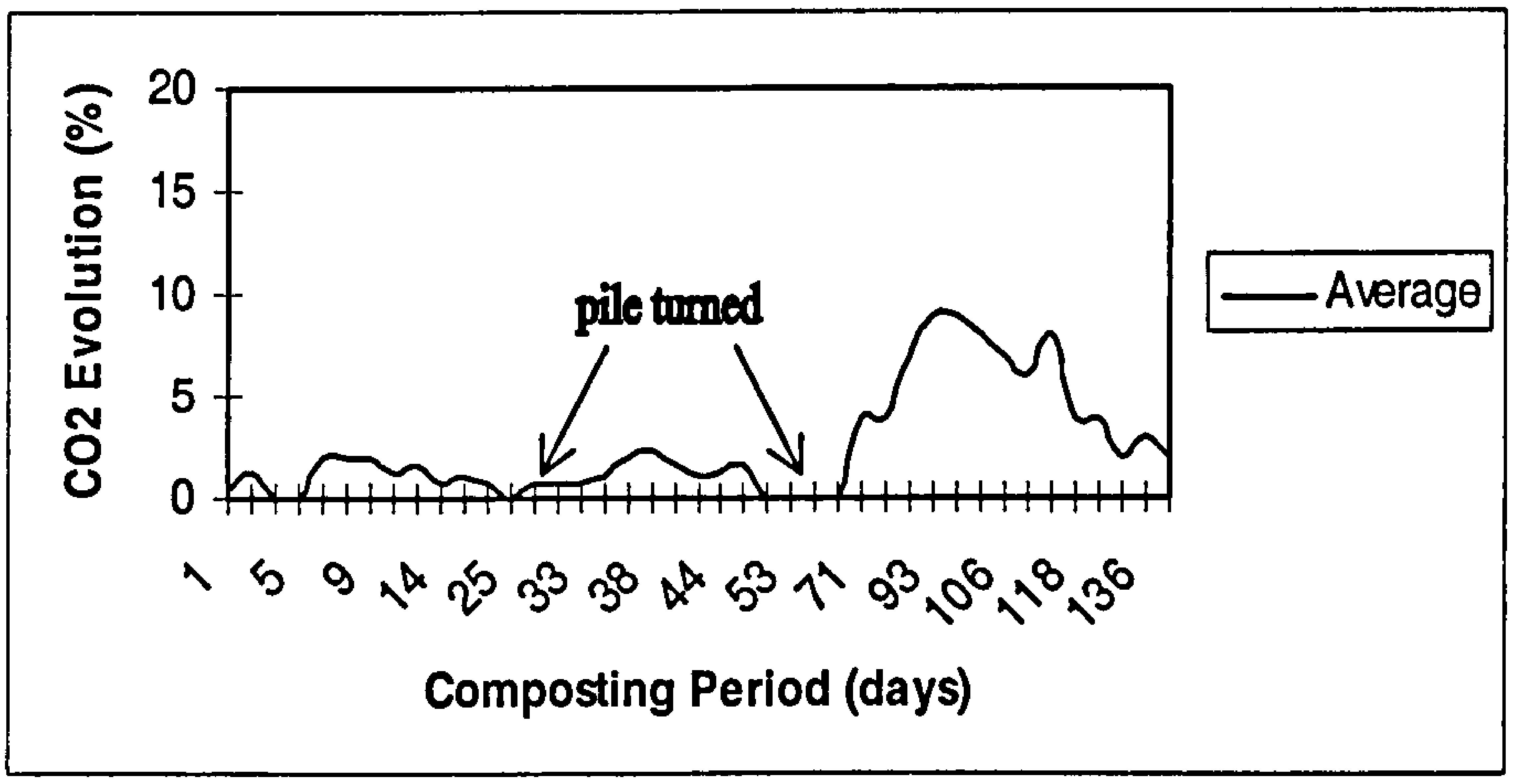

Figure 4.30. CO$_2$ Evolution within the 40% Cement Dust Pile, Phase 1

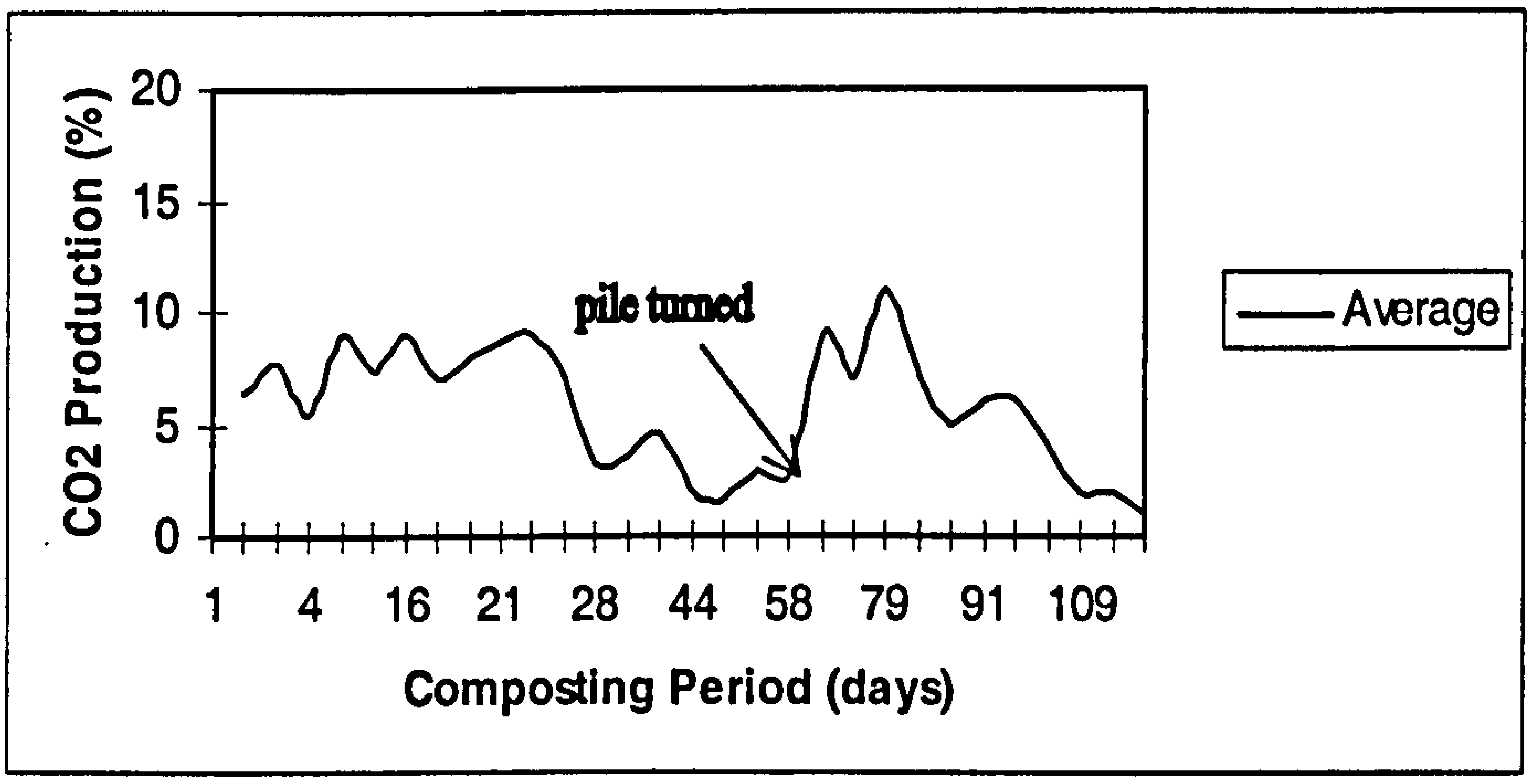

Figure 4.31. CO$_2$ Evolution within the 10% Cement Dust Pile, Phase 2

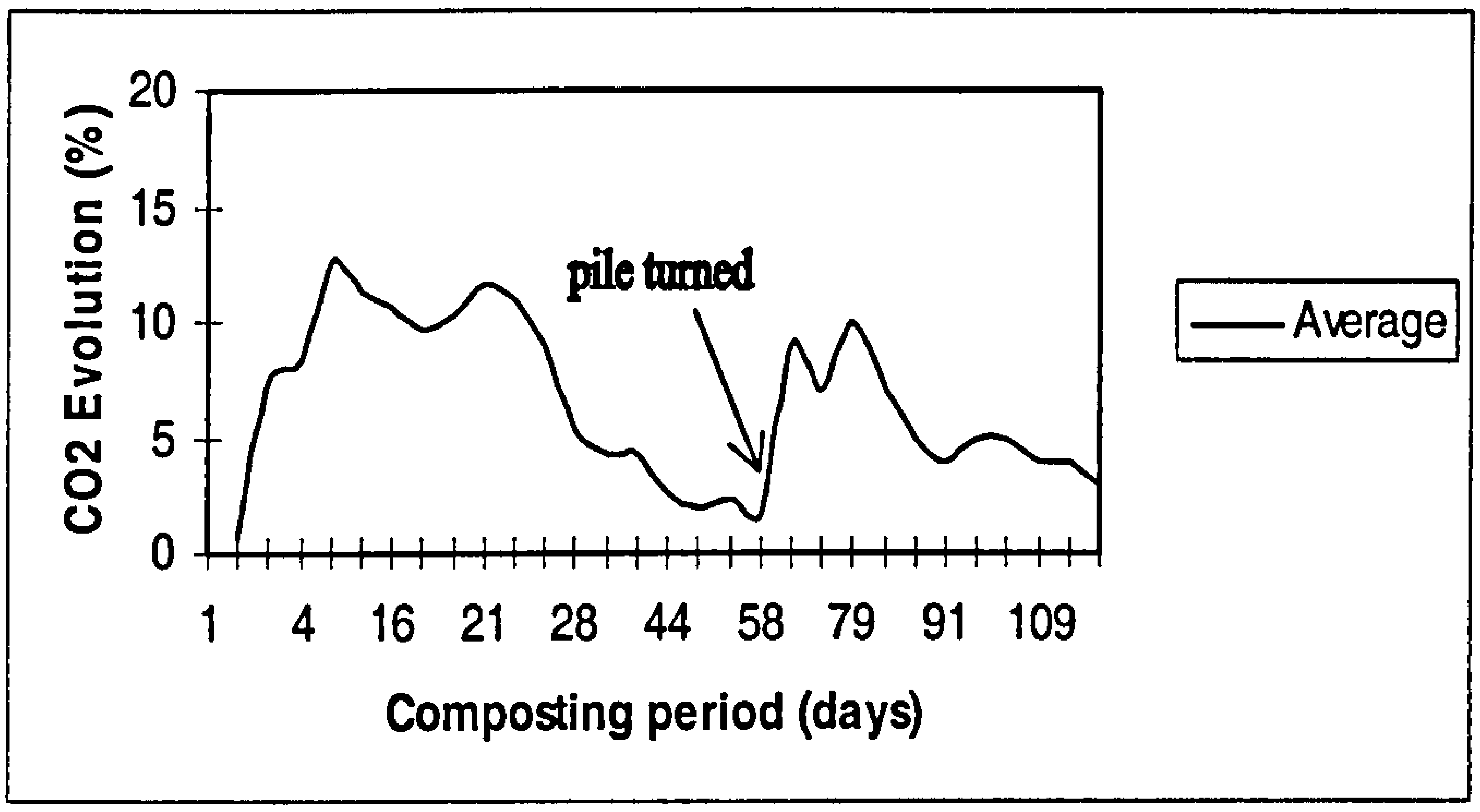

Figure 4.32. CO_2 Evolution within the 20% Cement Dust Pile, Phase 2

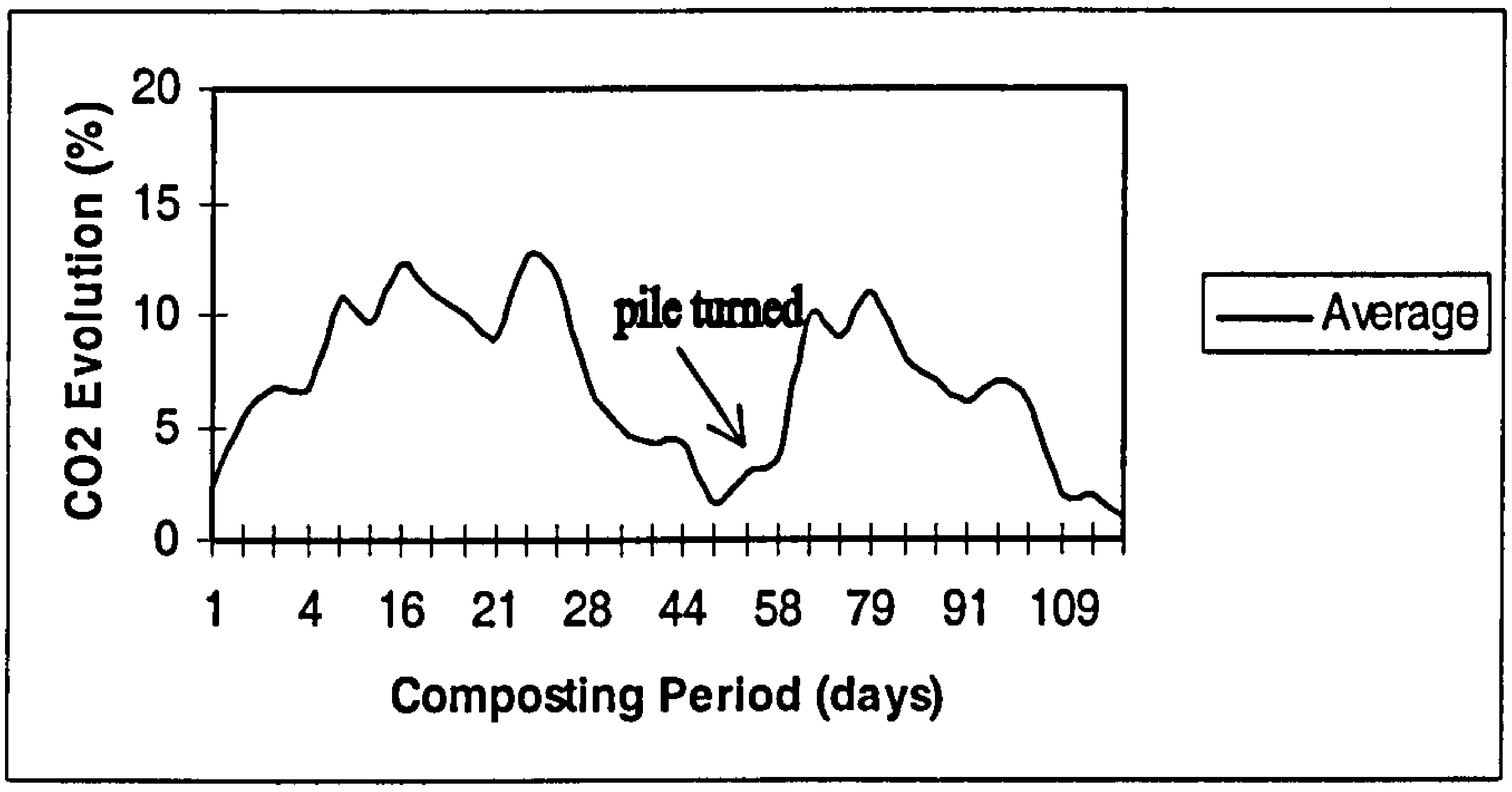

Figure 4.33. CO_2 Evolution within the 25% Cement Dust Pile, Phase 2

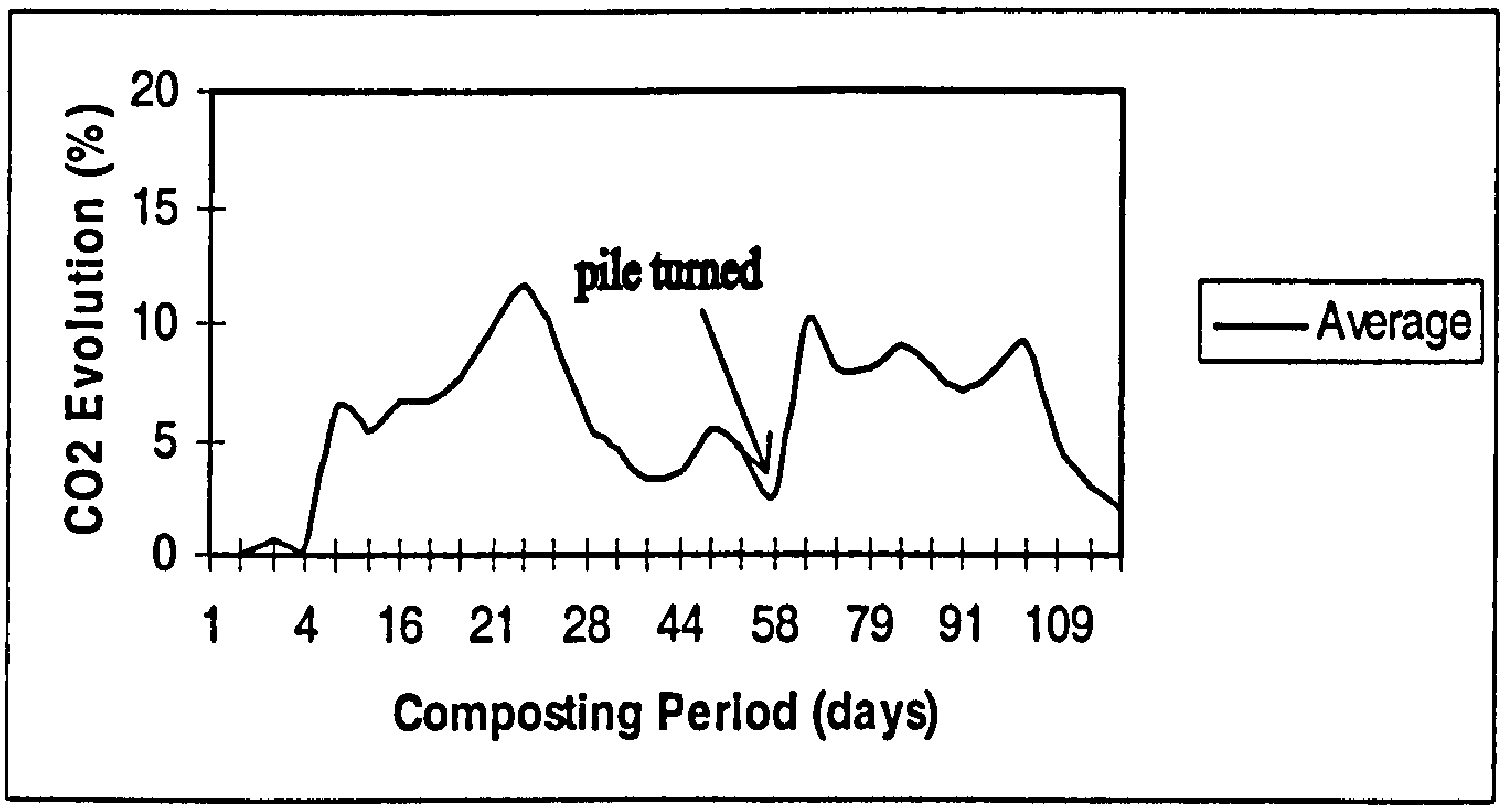

Figure 4.34. CO_2 Evolution within the 35% Cement Dust Pile, Phase 2

Figures 4.35 & 4.36 show the CO_2 trend for the 50% cement dust pile and the 30% cement dust pile without bulking agent of phase 2, respectively. For the 50% cement dust pile, there was a little bacterial activity and hence low rate of organic matter degradation has taken place during the fermentation stage. CO_2 levels fluctuated between 0 % and 2% during the fermentation stage. During the maturation stage and after turning, the CO_2 evolution percentage fluctuated between 0% and 6% until the end of the composting process.

For the 30% cement dust pile without bulking agent, bacterial activity started after about two weeks of composting, however, during the fermentation stage this pile did not give a good indication that the digestion process was proceeding. Average CO_2 percentage ranged from 0% to 3%, however these readings fluctuated during the fermentation stage. During the maturation stage, CO_2 levels increased rapidly and ranged from 9% to 3% at the end of the maturation stage. The low digestion process during the fermentation stage was expected due to the very low porosity and very high moisture content of the formed pile. No air space was available for the aerobic bacteria to start breaking down the organic matter, and this was confirmed during air sampling using the hand suction pump, when no air was being pumped out of the pile. Accordingly, the anaerobic bacteria were operating during this period, which was clear from the unpleasant odour emerging from the pile due to the formation of methane and hydrogen sulphide. As time elapsed, temperatures were elevated due to the cement effect referred to in section 4.2.1.1, and the moisture content decreased gradually, reaching an acceptable level that allowed the circulation of air inside the pile.

For the 35% to 50% cement dust concentration piles, the composting process was delayed for 4 to 7 days, respectively. This delay was made clear by the low CO_2 evolution measurements, rather than in that case the misleading temperature readings. During the fermentation process, the 40% and 50% cement dust piles indicated a low CO_2 evolution percentage (0% to 3%) which means that the microflora did not favor the compost piles' environment and not digesting the organic matter. The unfavourable conditions were due to the high pH and temperatures, and the frequent loss of moisture content (dehydration effect of cement dust). The bacteria started to digest the waste, however at a slow rate, as the conditions became more favourable. For the pile containing 30% cement dust and sludge without bulking agent, the conditions were not favouring the aerobic bacteria in digesting the waste. Very low porosity and high moisture content did not allow the circulation of air inside the pile. As temperatures were elevated for long periods of time, the moisture content decreased to acceptable levels to allow the circulation of air and the aerobic bacteria to digest the waste.

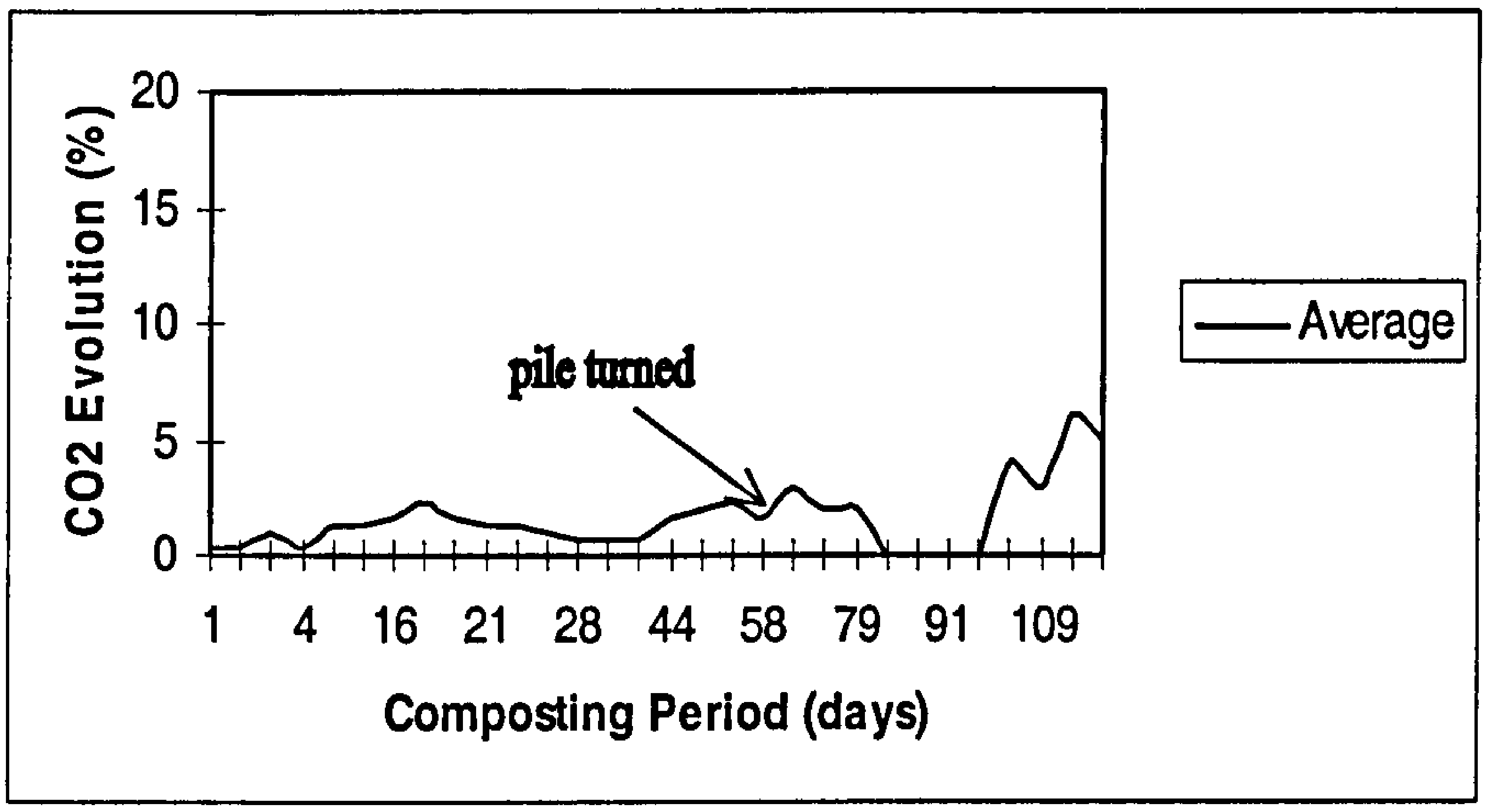

Figure 4.35. CO_2 Evolution within the 50% Cement Dust Pile, Phase 2

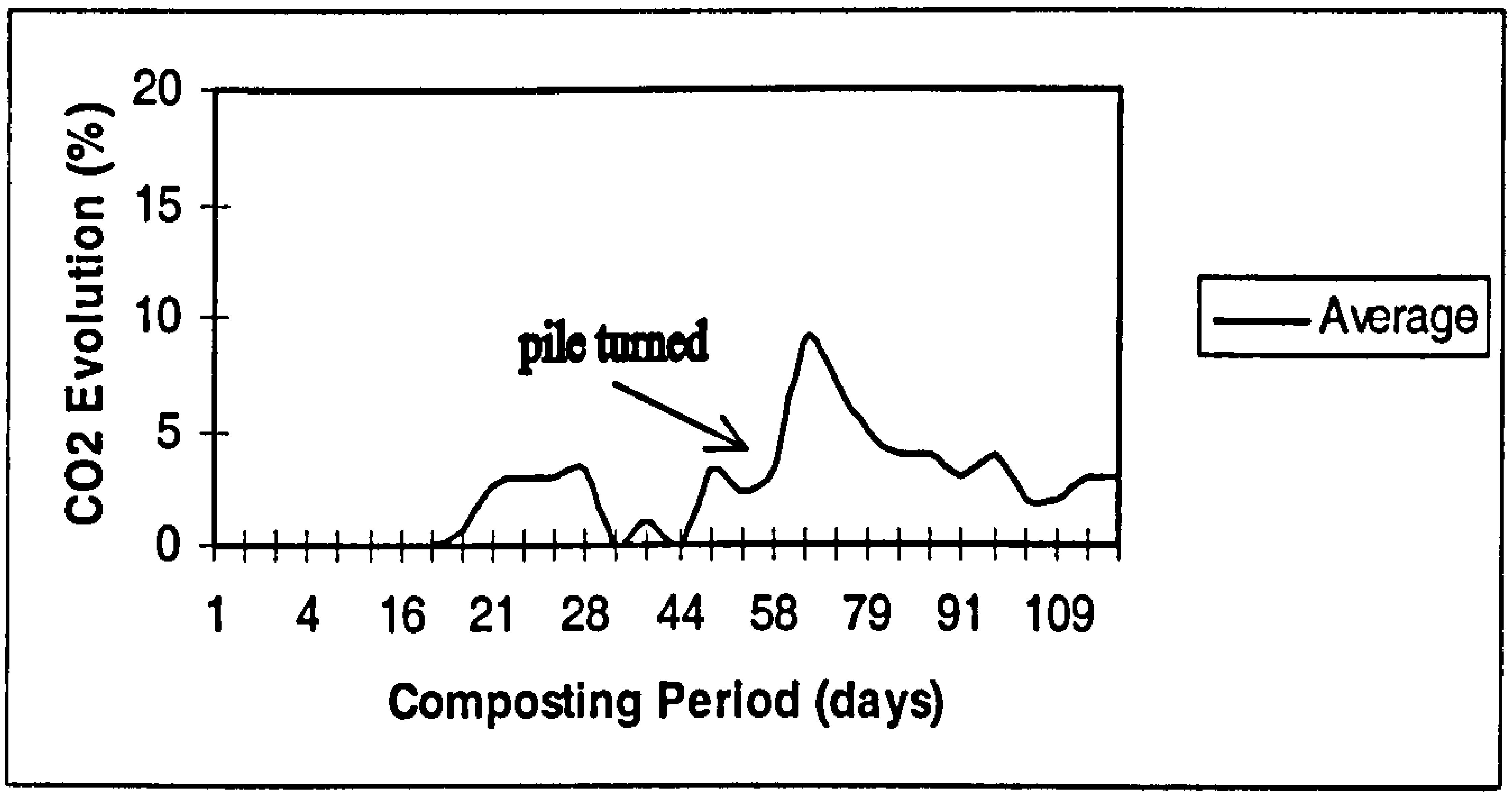

Figure 4.36. CO_2 Evolution within the 30% Cement Dust Pile without Bulking Agent, Phase 2

4.2.1.3. Physical & chemical changes

a. Changes in compost volume

A major benefit of composting is waste volume reduction, which usually ranges between one-quarter to more than one-half of the initial volume. This reduction depends mainly on the raw materials and the success of the treatment. Part of the volume reduction is represented by the loss of CO_2 and water to the atmosphere and the other part is the conversion of the loose, bulky materials into fine textured compost. Accordingly, the determination of the volume reduction percentage is another indication of how successful the digestion process has been and of the final compost quality.

During the composting period, measurements of the piles' height were taken during phases 1 and 2 and the results are shown in **Tables 4.6 & 4.7**, respectively. Height was measured at day one (initial height), at the end of the fermentation stage (day 66), after turning of the piles, one month after the start of the maturation stage (day 90), and at the end of the maturation stage (day 120). Piles' height was measured at the middle of the pile, from the invert of the central ventilation pipe to the highest point of the pile. After the removal of the ventilation pipes, the height was measured at the middle, from the ground level to the highest point of the pile.

For Phase 1, Table 4.6 shows the measurements taken for all the piles. During the fermentation stage, an estimated volume reduction of 59.6% and 56.1% occurred for the windrow and passive piles, respectively. During the maturation stage, an estimated volume reduction of 45.3% and 52.9% occurred for the windrow and passive piles, respectively. Accordingly, throughout the composting process, an estimated total volume reduction of 60.6% and 62.6% for the windrow and passive piles has occurred, respectively. The overall volume reduction of the passive pile was greater than the windrow pile, due to the more favourable conditions, rather than the normal decrease in decomposition rate that the windrow pile exhibited as a result of the limited oxygen content.

Table 4.6. Height & Volume Reduction Percentage during Composting for Phase 1 Piles.

Stage	Composting Period (Days)	Treatment			
		S+BA (W)	S+BA (P)	S+BA+30%C	S+BA+40%C
		Height (cm.)*			
Fermentation	Initial	104	107	110	105
	66 [b]	42	47	55	58
	66 [a]	75	85	90	81
	Volume Reduction (%)	**59.6%**	**56.1%**	**50.0%**	**44.8%**
Maturation	90	54	56	59	64
	120	41	40	48	49
	Volume Reduction (%)	**45.3%**	**52.9%**	**46.7%**	**39.5%**
	Total Reduction (%)	**60.6%**	**62.6%**	**56.4%**	**53.3%**

* Height of piles measured in the middle, from the invert of the ventilation pipes to the highest point.

* After ventilation pipes removal, height measured in the middle, from the ground level to the highest point.

a: After turning of piles.

b: Before turning of piles.

Table 4.7. Height & Volume Reduction Percentage during Composting for Phase 2 Piles.

Stage	Composting Period (Days)	Treatment					
		S+BA+10%C	S+BA+20%C	S+BA+25%C	S+BA+35%C	S+BA+50%C	S+30%C
		Height (cm.)*					
Fermentation	Initial	97	95	98	100	102	80
	66 ^{b}	43	43	47	51	59	61
	66 ^{a}	74	76	78	82	91	87
	Volume Reduction (%)	**55.7**	**54.7**	**52.0**	**49.0**	**42.2**	**23.8**
Maturation	90	54	55	58	64	72	64
	120	40	40	42	45	54	56
	Volume Reduction (%)	**45.9**	**47.4**	**46.2**	**45.1**	**40.7**	**35.6**
	Total Reduction (%)	**58.8**	**57.9**	**57.1**	**55.0**	**47.1**	**30.0**

* Height of piles measured in the middle, from the invert of the ventilation pipes to the highest point.

* After ventilation pipes removal, height measured in the middle, from the ground level to the highest point.

a After turning of piles.

b Before turning of piles.

During the fermentation stage for the 30% and 40% cement dust piles, an estimated volume reduction of 50% and 44.8%, respectively, was experienced. During the maturation stage, an estimated volume reduction of 46.7% and 39.5% occurred for the 30% and 40% cement dust piles, respectively. By the end of the composting process, an estimated total volume reduction of 56.4% and 53.3% occurred for the 30% and 40% cement dust piles, respectively.

For Phase 2, Table 4.7 shows the measurements taken for all the piles. During the fermentation stage, an estimated volume reductions of 55.7%, 54.7%, 52%, 49% and 42.2% were experienced for the 10%, 20%, 25%, 35% and 50% cement dust piles, respectively. During the maturation stage, an estimated volume reductions of 45.9%, 47.4%, 46.2%, 45.1% and 40.7% were experienced for the 10%, 20%, 25%, 35% and 50% cement dust piles, respectively. By the end of the composting process, an estimated total volume reductions of 58.8%, 57.9%, 57.1%, 55% and 47.1% were experienced for the 10%, 20%, 25%, 35% and 50% cement dust piles, respectively. The 30% cement dust pile without bulking agent showed low volume reduction, 23.8% during the fermentation phase, 35.6% during the maturation phase and an estimated total volume reduction of 30% over the composting period.

Generally, for all the cement dust piles of phases 1 and 2, the higher the ratio of cement dust to sludge in the initial mix, the less volume reduction occurred. During the fermentation stage, the volume reduction of the low cement to sludge ratio piles was higher than for the high cement to sludge ratio pile, and this was mainly due to the lower content of cement dust that resulted in less inhibition of the microflora for degrading the organic matter. Moreover, higher CO_2 levels and lower loss of moisture resulted from the temperature elevations and dehydration effect of the cement dust. However, during the maturation stage, the opposite was the case. Due to the pH reduction from the 11.0 range to the 8.0 range, turning of the piles and moistening to compensate for the water losses, the high cement to sludge ratio piles should give relatively more volume reduction than the low cement to sludge ratio piles. This was due to the presence of a higher proportion of undigested matter due to the unfavourable conditions for the microflora to digest the organic matter (high pH and temperatures) during the fermentation stage. Accordingly, digestion started with temperature elevation and CO_2 formation that resulted in volume reduction. This was the case for the 10% and 20% cement dust piles, however, for the 25% and 30% cement dust piles, they acted in the same manner, but relative to each other. The 35%, 40% and 50% cement dust piles showed very similar volume reductions, averaging about 40%. Regarding the 30% cement dust pile without bulking agent, the conditions were unfavourable for aerobic digestion, with very high moisture content, low porosity, no oxygen available, as well as very low C:N ratio. Basically, during the fermentation stage, as has been shown from the temperature trend and CO_2 production levels, very little biological activity was shown during this stage. However, after turning, temperature elevation and loss of moisture content, the oxygen content increased within the pores, microflora started degrading the organic matter, and thus a volume reduction was observed. It is clear that the volume reduction was the lowest compared with those of all the other piles.

b. Changes in pH

pH is considered an indicative parameter for the composting process and the microbial activity. The changes in pH during the composting period are given in **Table 4.8** and are shown graphically in **Figures 4.37 & 4.38** for phases 1 & 2, respectively. Generally, the windrow and passive piles started at neutral pH initially, increased gradually and finally remained slightly alkaline at 8.83 and 8.25 for the windrow and passive piles, respectively. However, it is important to highlight the sudden increase of pH after 15 days, reaching 9.06 for the windrow pile. This is due to the biological activity that encouraged the formation of ammonia (ammonification) through the decomposition of nitrogenous organic matter. Regarding the cement dust piles with bulking agent as well as the cement dust pile without bulking agent, all started with an initial alkaline pH. The higher the ratio of cement dust, the higher the pH, which ranged between 8.4 for the 10% cement dust pile and 11.61 for the 50% cement dust pile. This is expected, due to the presence of CaO which, in the presence of water, is converted to $Ca(OH)_2$. The pH gradually decrease for 15 days of composting, except for the 10% cement dust pile which took a month, after which pH started to decrease, however still alkaline, ranging between 8 to 8.5. This gradual decrease in pH for all the cement dust piles is explained by the production of CO_2 and organic acids, the cement dust piles is explained by the production of CO_2 and organic acids, the conversion of $Ca(OH)_2$ to $CaCO_3$, and the conversion of ammonia to nitrites and nitrates.

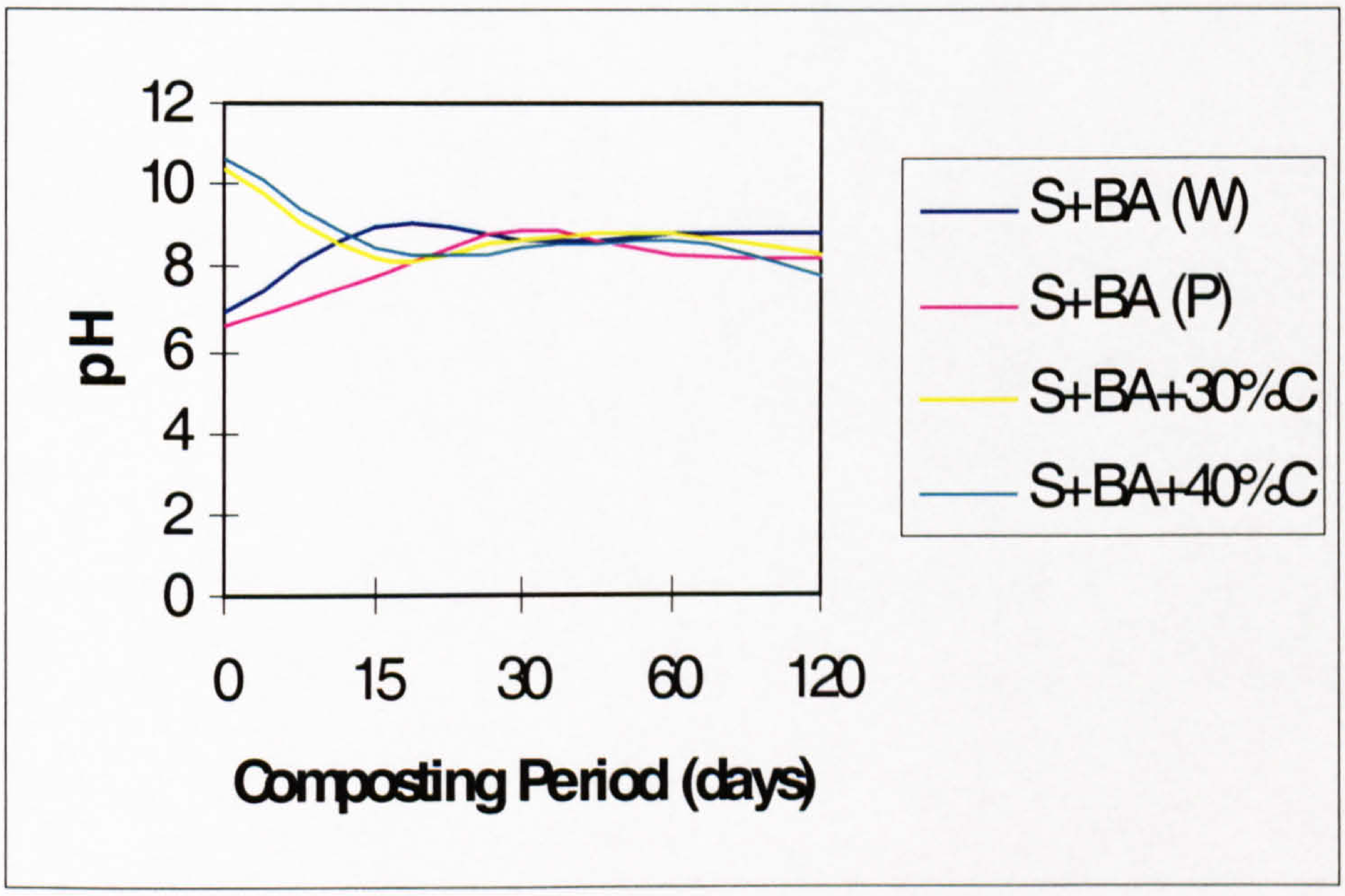

Figure 4.37. pH Changes during Composting of Phase 1 Piles

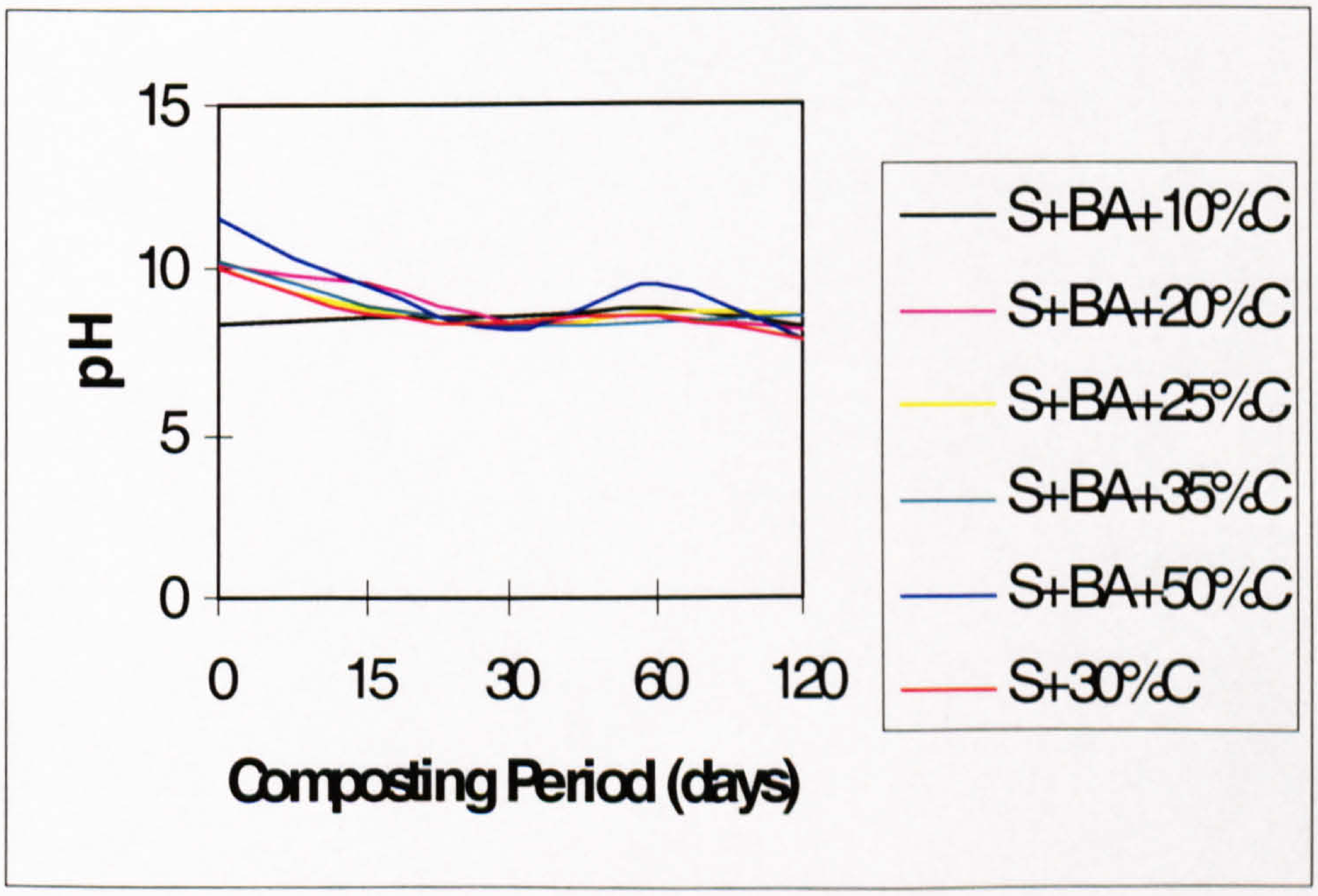

Figure 4.38. pH Changes during Composting of Phase 2 Piles

Table 4.8. pH Changes during Composting for Phases 1 & 2.

Phase	Treatment	pH during Composting (days)				
		Fermentation Stage				Maturation Stage
		0	15	30	60	120
Phase 1	S+BA (W)	6.91	9.06	8.65	8.84	8.83
	S+BA (P)	6.61	7.81	8.93	8.42	8.25
	S+BA+30%C	10.35	8.25	8.70	8.81	8.37
	S+BA+40%C	10.69	8.46	8.45	8.71	7.84
Phase 2	S+BA+10%C	8.40	8.59	8.51	8.87	8.27
	S+BA+20%C	10.23	9.58	8.42	8.50	8.08
	S+BA+25%C	10.01	8.86	8.21	8.62	8.59
	S+BA+35%C	10.37	8.92	8.22	8.46	8.59
	S+BA+50%C	11.61	9.56	8.07	9.46	7.89
	S+30%C	10.00	8.72	8.45	8.57	7.90

c. Changes in organic matter

The organic matter is another essential indicator of the microbial activity, the degradation of the materials, and the success of the treatment. According to several researchers (Hassouneh et al., 1999; Iacobani et al., 1984), the maturity of the compost is judged with several parameters, most important of all are the organic matter and C/N ratio. The compost is considered to be stable with a more than 50% reduction in the organic matter content. The losses in organic matter during the composting period have been calculated for the fermentation and maturation stages, as well as the total losses for all the piles. Data in **Table 4.9**, illustrated by **Figures 4.39 and 4.40**, show the changes in organic matter for phases 1 & 2, respectively. For phase 1, the windrow and passive piles showed 38.06% & 45.99% of organic matter loss respectively during the fermentation phase, 26.95% & 14.95% during the maturation stage and a total loss of 54.75% & 54.05%, respectively, over the composting period. This indicates that the passive pile had better performance and higher organic degradation rate than the windrow pile during the fermentation phase, due to the more favourable conditions. However, after turning and during the maturation stage, the windrow pile showed higher organic matter loss, and thus higher microbial activity, which is expected due to the temporarily aerobic conditions and the availability of undegraded organic matter. However, at the end of the composting period, both piles had nearly the same organic matter loss.

During the fermentation stage for the cement dust piles, organic matter losses of about 33% to 51% occurred. During the maturation stage, organic matter losses of about 18% to 31% occurred and total losses of about 54% to 60% over the composting period. For the fermentation stage, all piles showed very similar organic matter losses, however, for the 35% to 50% cement dust piles, lower organic matter losses was obtained, the lowest being the 50% cement dust pile. For the maturation stage, the 50% cement dust pile was the awkward pile, with greater destruction of organic matter reaching 31.1%. However, at the end of the composting period, all piles produced similar results, the lowest being the 35% to 50% cement dust piles, which showed 53% to 55% total organic matter losses.

For the 30% cement dust pile without bulking agent, the organic matter loss during the fermentation stage was 27.13%, plus 34.89% during the maturation stage, and the total loss over the composting period was 52.55%. This pile showed the lowest organic matter loss due to the generally unfavourable conditions that even stopped microbial activity during most of the fermentation stage. The build up of temperature and CO_2 production (refer to sections 4.3.1.1 & 4.3.1.2) give an indication of the microbial activity, but this was during the maturation stage.

Generally, the lower decomposition rates during the fermentation stage of composting for some of the piles was mainly due to the thermal inhibition of the microbiological activities during the period characterised by high temperature range (65-73°C) above the optimum thermophilic range (45-60°C), the high pH, as well as maybe the change in compost microflora (transition between the mesophilic and thermophilic stages). This has been enhanced by the dehydration effect of the cement dust (>30% cement concentrations). According to De Bertoldi et al. (1985) and Rynk (1992), thermophilic microorganisms degrade organic materials most efficiently below 60°C.

d. Changes in C/N ratio

C/N ratio is a very good indicator of compost stability and maturity. The C/N ratio falls gradually during composting and, according to De Bertoldi et al. (1983) a compost is ready to be applied on land when the C/N ratio is less than 15:1. The changes in the C/N ratio during the composting period for phases 1 & 2 are shown in **Table 4.10**. The ratios of carbon to nitrogen are calculated from the available data of organic matter (OM) and total nitrogen (TN) percentages that were determined during the composting period, whereas the organic carbon (OC) is considered to be 58% of the organic matter (OM) according to Black et al. (1965). Accordingly, the relationship between OC and OM could be expressed as follows:

$$OC = OM/1.7241$$

The initial C/N ratio for phase 1 & phase 2 piles should have been 25.7:1 and 24.3:1, respectively, according to the initial mixing ratios of sludge to bulking agent, in order to achieve favourable composting conditions (refer to section 3.6.2.1). However, as shown in Table 4.10 and **Figures 4.41 & 4.42** for phases 1 and 2, respectively, the initial measured C/N ratios varied from the calculated values for the mixtures. This is mainly due to difficulty in collecting a homogenous sample, however, the variations were not major.

The initial C/N ratios were 25.9:1 & 26.1:1 for the windrow and passive piles, respectively, 13:1 & 11.7:1 at the end of the fermentation stage, and 11.8:1 & 10.2:1 at the end of the maturation stage. The final C/N ratios indicate the stability of the final compost and that the carbon and nitrogen contents of the mixture have been well digested and degraded.

Regarding the cement dust piles, the initial C/N ratios ranged between 24.0:1 and 25.1:1, 11.5:1 & 16:1 at the end of the fermentation stage, and 10.2:1 & 14.6:1 at the end of the maturation stage. Generally, all piles showed a final low C/N ratio that is favourable and acceptable for land application. The highest C/N ratio achieved was for the 50% cement dust pile (14.6:1).

For the 30% cement dust pile without bulking agent, the initial C/N ratio was 13.5:1. After the fermentation stage the C/N decreased to 11.5:1, and at the end of the maturation stage reached 10.2. According to the content of the carbon to nitrogen ratio, the bacteria decomposed the available matter, however at a very low decomposition rate, probably due to the deficiency of essential nutrients for the digestion process.

Table 4.9. Organic Matter Percentage Changes during Composting of Phases 1 & 2.

Phase	Treatment	Organic Matter % during Composting (days)							
		Fermentation Stage					Maturation Stage		
		0	15	30	60	Fermentation Loss (%)	120	Maturation Loss (%)	Total Loss (%)
Phase 1	S+BA (W)	75.72	50.69	47.77	46.90	38.06	34.26	26.95	54.75
	S+BA (P)	77.72	51.91	47.02	41.98	45.99	35.71	14.94	54.05
	S+BA+30%C	71.58	50.27	48.57	41.83	41.56	32.21	23.00	55.00
	S+BA+40%C	68.17	57.22	44.98	42.52	37.63	31.40	26.16	53.95
Phase 2	S+BA+10%C	71.12	60.10	48.52	41.07	42.25	32.05	21.96	54.94
	S+BA+20%C	67.58	56.98	39.84	32.83	51.42	26.81	18.34	60.33
	S+BA+25%C	67.38	56.62	43.41	35.26	47.67	28.71	18.58	57.39
	S+BA+35%C	66.90	53.93	50.77	41.24	38.35	29.85	27.62	55.38
	S+BA+50%C	63.07	54.81	42.38	42.45	32.70	29.26	31.10	53.62
	S+30%C	62.93	54.34	51.03	45.86	27.13	29.86	34.89	52.55

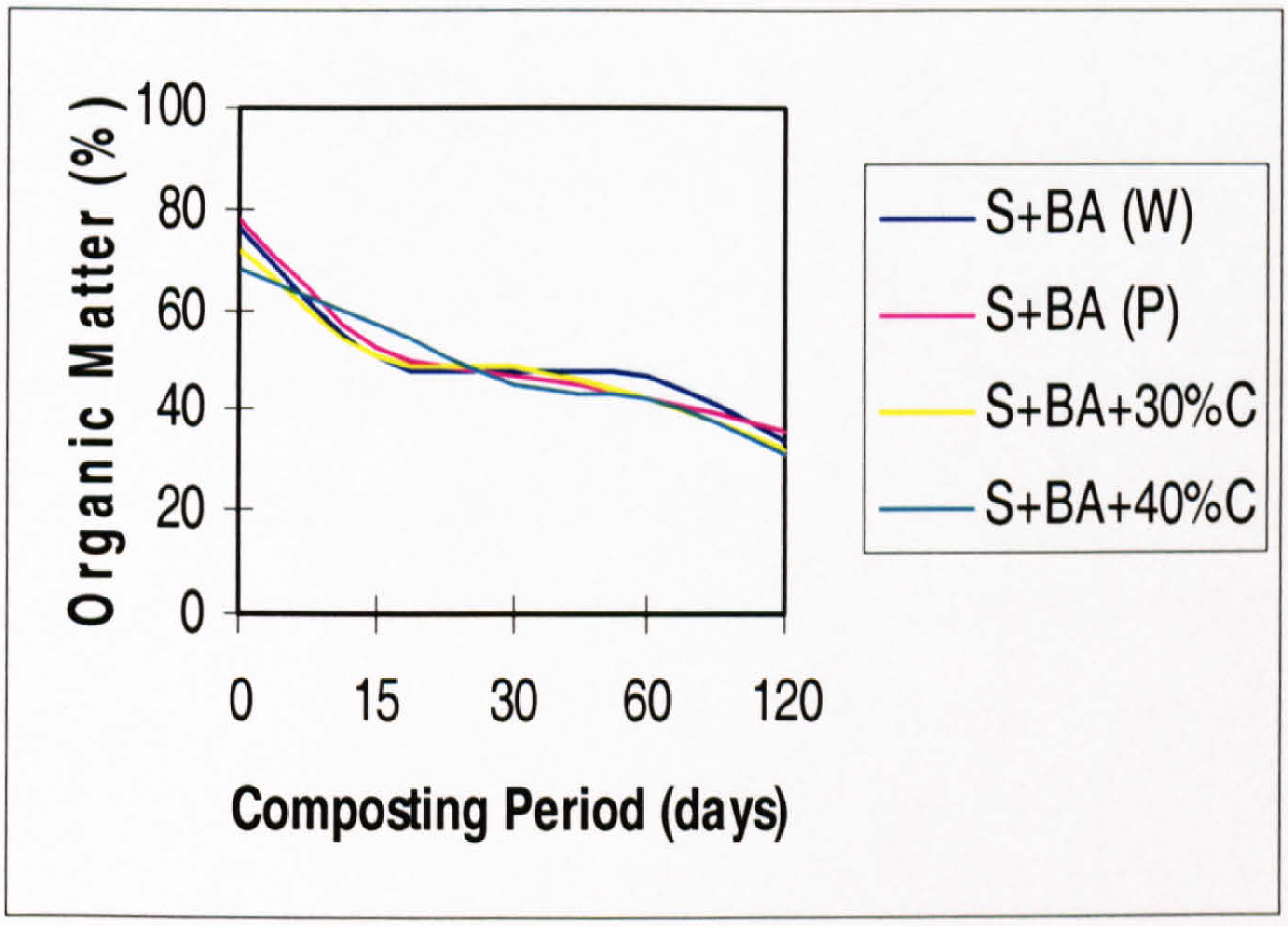

Figure 4.39. Organic Matter Changes during Composting of Phase 1 piles

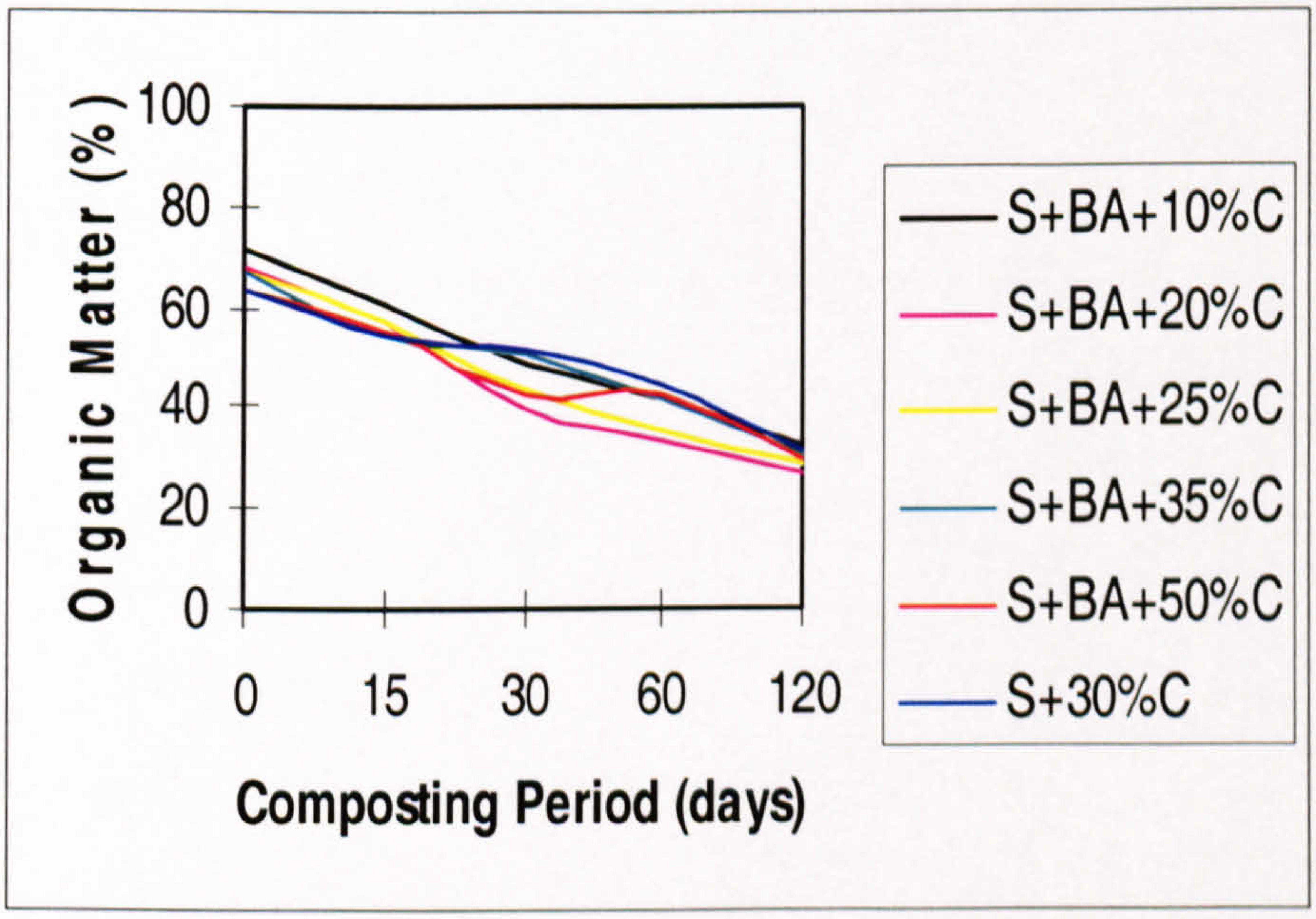

Figure 4.40. Organic Matter Changes during Composting of Phase 2 Piles

Table 4.10. C/N Ratio Changes during Composting for Phases 1 & 2.

Phase	Treatment	C/N Ratio Changes during Composting (days)				
		Fermentation Stage				Maturation Stage
		0	15	30	60	120
Phase 1	S+BA (W)	25.9	17.4	16.2	13.0	11.8
	S+BA (P)	26.1	16.5	16.1	11.7	10.2
	S+BA+30%C	27.2	21.4	17.9	15.9	13.4
	S+BA+40%C	24.0	21.9	20.1	14.6	12.8
Phase 2	S+BA+10%C	24.9	23.2	21.0	11.8	10.2
	S+BA+20%C	24.5	22.5	17.8	11.5	10.5
	S+BA+25%C	24.6	20.8	16.1	14.1	11.7
	S+BA+35%C	25.1	22.4	18.2	13.4	11.8
	S+BA+50%C	24.9	20.6	16.9	16.0	14.6
	S+30%C	13.5	13.2	12.4	11.5	10.2

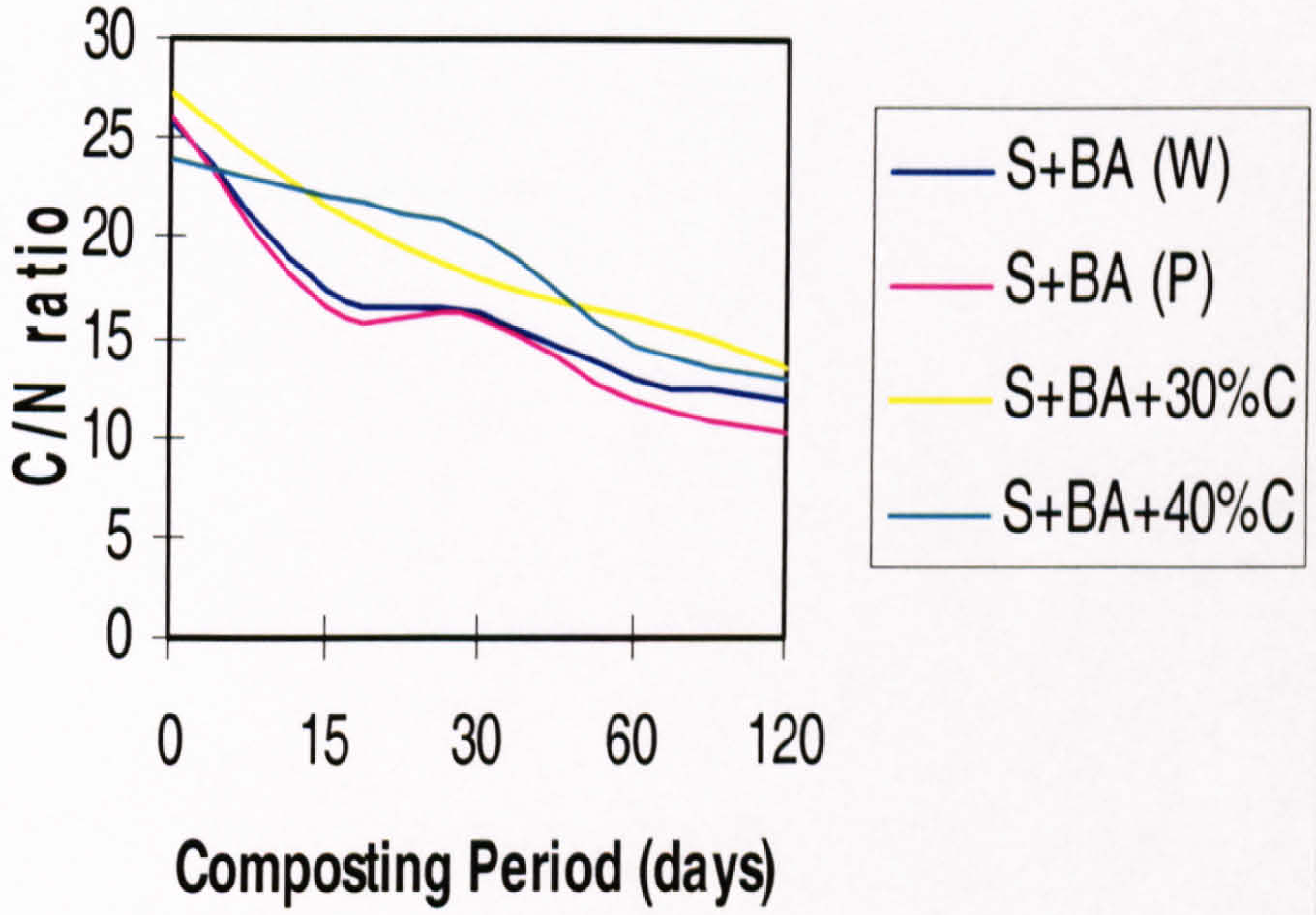

Figure 4.41. Changes in C/N Ratio during Composting of Phase 1 Piles

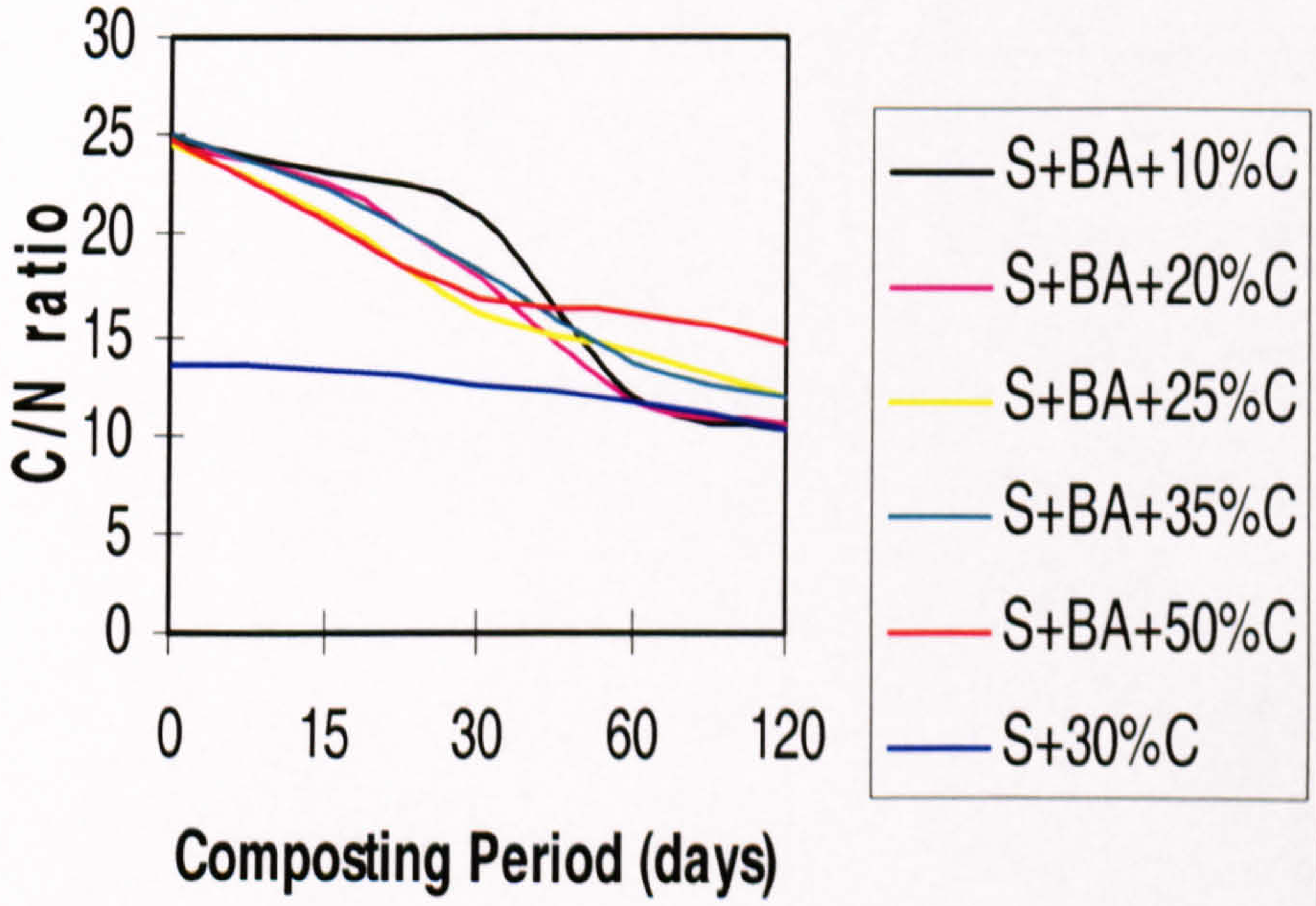

Figure 4.42. Changes in C/N Ratio during Composting of Phase 2 Piles

e. Changes in total nitrogen

The changes in Total Nitrogen percentages during composting are shown in **Table 4.11** and **Figures 4.43 & 4.44** for phases 1 & 2, respectively. The percentages of nitrogen increased for the passive, windrow, 10%, 20% and 40% cement piles during the fermentation stage. However, for the other piles, a slight decrease in nitrogen content is noticed but this decrease does not indicate that there is an actual reduction in the nitrogen content, since there has been an actual decrease in the organic matter content, averaging between 33% to 51% during the fermentation stage (refer to section c).

At the end of the composting process, the nitrogen content increased for the passive and the 10% cement dust piles by about 17% and 10%, respectively. For the other piles, a decrease in nitrogen content occurred, ranging between about 1% for the windrow pile and 41% for the 50% cement dust pile. Again this decrease is not an indication that there is an actual loss of nitrogen content in the compost, due to the actual decrease of organic matter, ranging between about 52% and 60% by the end of the composting process (refer to section c).

Generally, continuous degradation of organic matter as well as consumption of nitrogen was taking place during the composting period. The higher the C:N ratio of the mix, the lower the nitrogen loss. Moreover, nitrogen is lost by volatilisation during the high temperature phase, as well as by the leaching after piles' moistening. Almost all the nitrogen lost during composting results from the release of ammonia, formed from organic nitrogen compounds. Additional nitrogen may be lost by denitrification, which produces nitrogen gas (N_2) under anaerobic conditions. However, nitrogen losses from denitrification are expected to be minor.

De Bertoldi et al. (1983) and Amer (1993) have reported nitrogen losses from sewage sludge during microbial activity and have concluded that mainly proteinaceous materials are decomposed in the initial stages of decomposition. However, according to Rynk (1992), nitrogen losses are due to the release of ammonia. The ammonia determinations in this study are in agreement with these investigators' explanations and the losses in nitrogen content support this view.

Table 4.11. Total Nitrogen Percentage Changes during Composting for Phases 1 & 2.

Phase	Treatment	Total Nitrogen % during Composting (days)							
		Fermentation Stage					Maturation Stage		
		0	15	30	60	Loss or Gain (%)*	120	Loss or Gain (%)*	Total Loss or Gain (%)*
Phase 1	S+BA (W)	1.696	1.690	1.710	2.092	+ 23.385	1.684	- 19.520	- 0.699
	S+BA (P)	1.727	1.825	1.694	2.081	+ 20.495	2.030	- 2.441	+ 17.554
	S+BA+30%C	1.526	1.363	1.574	1.526	- 0.045	1.394	- 8.635	- 8.676
	S+BA+40%C	1.648	1.516	1.298	1.689	+ 2.521	1.163	- 31.128	- 29.391
Phase 2	S+BA+10%C	1.657	1.503	1.340	2.019	+ 1.853	1.823	- 9.714	+ 10.016
	S+BA+20%C	1.600	1.469	1.298	1.656	+ 3.478	1.481	- 10.552	- 7.440
	S+BA+25%C	1.589	1.579	1.564	1.450	- 8.703	1.423	- 1.881	- 10.420
	S+BA+35%C	1.546	1.396	1.618	1.492	- 3.495	1.170	- 21.548	- 24.290
	S+BA+50%C	1.469	1.543	1.454	1.254	- 14.615	0.862	- 31.254	- 41.301
	S+30%C	2.704	2.388	2.387	2.212	- 18.180	1.777	- 19.651	- 34.259

* Negative sign indicates loss, positive sign indicates gain.

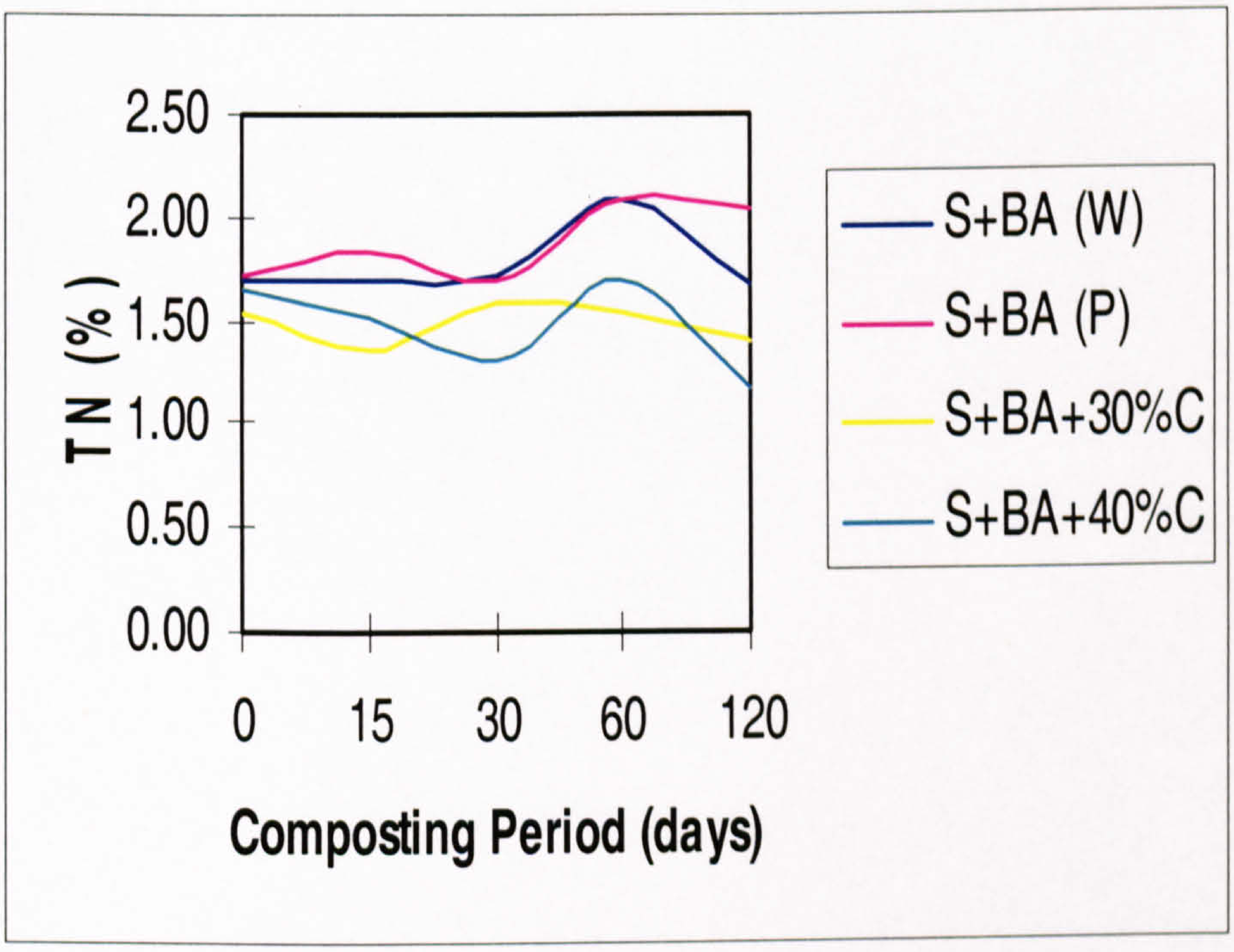

Figure 4.43. Changes in Total Nitrogen during Composting of Phase 1 Piles

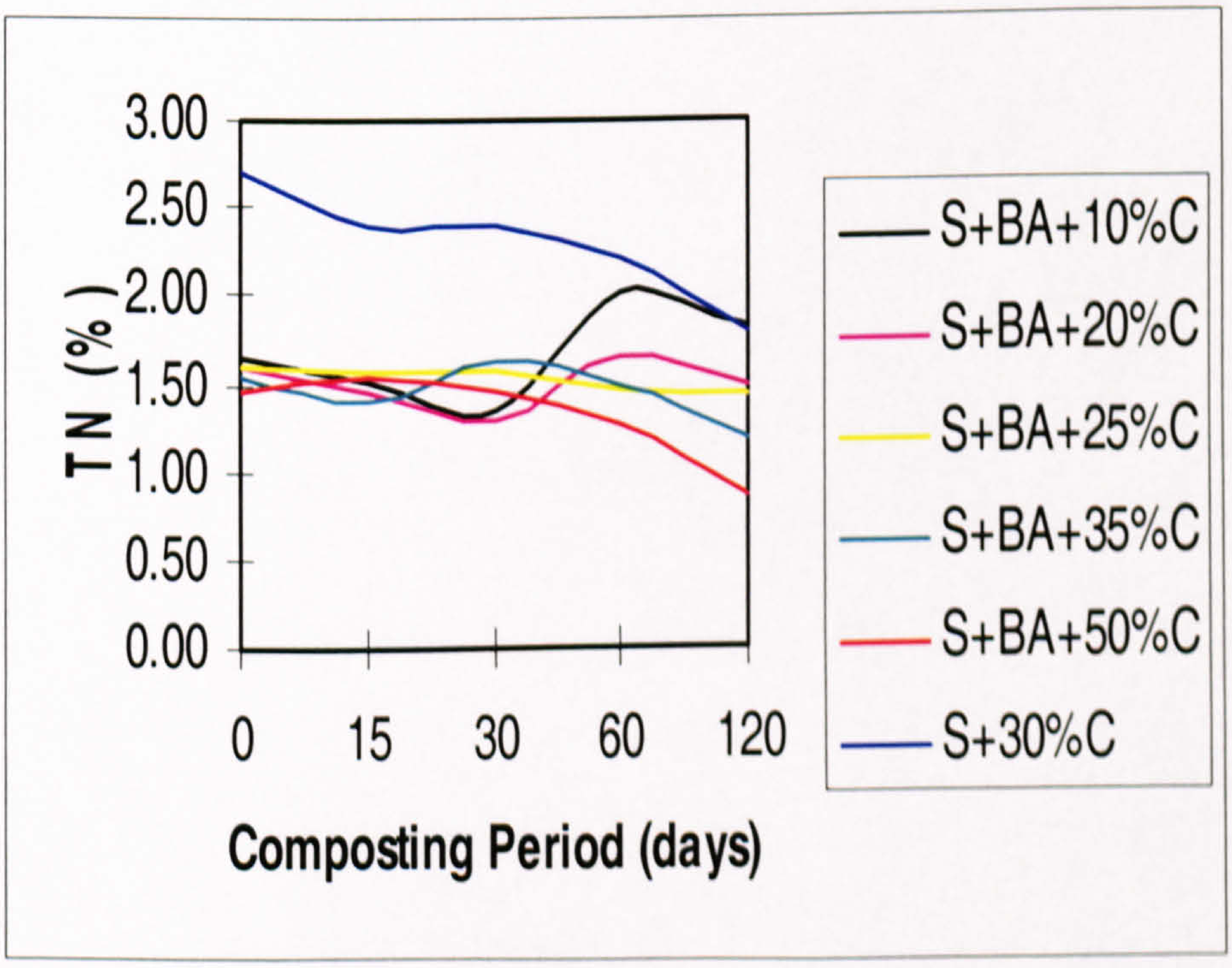

Figure 4.44. Changes in Total Nitrogen during Composting of Phase 2 Piles

f. Changes in ammoniacal nitrogen

Data in **Table 4.12** illustrated in **Figures 4.45 to 4.54** show the changes in ammoniacal nitrogen during the composting period. After 15 days of active composting, a high release of ammonia can be noticed for all the piles, except for the 30% cement dust pile without bulking agent, which showed the highest release of ammonia after one month. The general trend for the production of ammonia is an increase, giving the highest value after 15 days of composting, thereafter starting to decrease until the end of the maturation stage. The initial ammonia content was highest for the 10% cement dust pile, at 2516 mg/l, the lowest being for the 30% cement dust pile without bulking agent, at 916 mg/l, with the other piles falling between these levels. After 15 days of composting, the 50% cement dust pile showed the highest release of ammonia, reaching 6729 mg/l, and the 30% cement dust pile without bulking agent showed the lowest ammonia release, of 1420 mg/l, the other treatments being in between. However, the windrow and passive piles showed normal initial ammonia levels of 2092 and 2303 mg/l, respectively, and after 15 days of active composting the highest release of ammonia was recorded, being 2534 and 2870 mg/l for the windrow and passive piles, respectively.

It is important to highlight the effect of the cement dust on the production and loss of ammonia. The higher the cement dust concentration, the higher the pH and the higher the loss of ammonia. Two forms of ammonia are present in the composting materials: gaseous ammonia (NH_3) and the ammonium ion (NH_4^+), which stays dissolved within the compost pile. Both forms are present and can be converted from one to the other. A higher pH (fewer H ions) favours the gaseous ammonia form, which can escape from the pile. Accordingly, to avoid excessive ammonia loss, the initial pH of the mix should be as close as possible to neutral, and not more than 8.5, according to Rynk (1992) and Amer (1993).

According to Amer (1993), Counts et al. (1975) and Jeffrey et al. (1990) confirmed that the nitrogen content of sewage sludge was reduced on mixing and storage with alkaline admixture such as cement dust or lime, due to the release of gaseous ammonia. Moreover, they added that from the point of view of the microbiologist, the ammonia release that occurs has a great effect in disinfection of the treated sludge. Amer (1993) also confirmed the same findings, that the higher the cement dust concentration, the higher the loss of ammonia and thus the higher reduction of nitrogen content at the end of the composting period

Generally, ammonia is generated as a result of the activity of microorganisms in decomposing the organic matter containing protein and thus producing ammonia (ammonification process). The subsequent decrease in ammoniacal nitrogen is due to the continuous aeration, which may oxidise ammonia to nitrites and nitrates, as well as assisting in the release of ammonia to the atmosphere.

g. Changes in nitrate

The general trend for nitrate production is the opposite of ammonia release. **Table 4.13** shows the changes in nitrate throughout the composting process for phases 1 & 2. Graphical illustrations of the data are shown in **Figures 4.45 to 4.54**, with the ammoniacal changes. Generally, nitrate gradually decreased from day one, reaching 0 mg/l after one month of active composting. By the end of the fermentation stage, and throughout the maturation stage, nitrate started to appear. The highest value for nitrate after the maturation stage was for the 10% cement dust pile, at 122 mg/l, and the lowest nitrate value was for the 50% cement dust pile, at 16 mg/l, other treatments being in between these levels. The appearance of nitrate at the end of the fermentation stage and during the maturation stage is explained by the fact that the nitrifying bacteria which are responsible for the conversion of the ammonia to nitrate, referred to as the nitrification process, are inactive and have a slow growth rate at temperatures greater than 40°C. Accordingly, they will start to become active normally after the reactions of organic waste decomposition are complete and the elapse of the thermophilic phase. Moreover, the higher the cement dust concentration, the lower the nitrate concentration. This is mainly due to the high loss and volatilisation of ammonia to the open air.

Since nitrate is the form of nitrogen which is readily available for crop uptake, the maturation phase thus becomes an essential step in composting to produce good quality compost.

h. Changes in heavy metals & trace elements

Although heavy metals content and the effect of cement dust on its concentration is not the subject of this research, it is important to analyse the heavy metals content before and after composting treatment of sewage sludge, in order to judge the final compost quality.

Initial samples from the filter pressed sludge (raw sewage sludge) and a composite sample from all the cement piles (windrow, passive and 30% cement dust pile without bulking agent were excluded from the composite sample) at the end of the maturation stage and after 120 days of composting were analysed for heavy metals content. The measured concentrations of Fe, Mn, Cu, Zn, Pb, Ni, Cr and Hg in the raw sludge and in the final treated compost are shown in **Table 4.14.**

As shown in Table 4.14, the concentrations of all heavy metals after composting have been decreased. This is due to the diluting effect of adding the bulking agent and possibly due to the addition of cement dust. Jeffrey et al. (1990) and Garcia et al. (1990) and (1991), according to Amer (1993), investigated this issue and confirmed that the increase in pH of the sludge upon the treatment with cement dust and lime results in a significant reduction in heavy metals' solubility, as the metals exhibit minimum solubility at high pH.

All heavy metals are within the Egyptian regulatory standards, except for lead which initially exceeded the limits.

Table 4.12. Ammoniacal Nitrogen Changes during Composting for Phases 1 & 2.

Phase	Treatment	Ammoniacal Nitrogen Changes during Composting (mg/l)				
		Fermentation Stage				Maturation Stage
		0	15	30	60	120
Phase 1	S+BA (W)	2092	2534	2276	948	837
	S+BA (P)	2303	2870	2507	1270	1109
	S+BA+30%C	1636	4690	890	657	485
	S+BA+40%C	1613	5768	670	489	340
Phase 2	S+BA+10%C	2516	3576	1754	1326	1073
	S+BA+20%C	2153	3750	1256	956	810
	S+BA+25%C	1982	4171	1098	853	678
	S+BA+35%C	1542	5243	750	568	429
	S+BA+50%C	1687	6729	589	451	261
	S+30%C	916	1420	3309	537	469

Table 4.13. Nitrate Changes during Composting for Phases 1 & 2.

Phase	Treatment	Nitrate Changes during Composting (mg/l)				
		Fermentation Stage				Maturation Stage
		0	15	30	60	120
Phase 1	S+BA (W)	268	52	0	57	69
	S+BA (P)	294	52	0	76	94
	S+BA+30%C	105	92	0	38	43
	S+BA+40%C	79	40	0	38	41
Phase 2	S+BA+10%C	105	78	0	108	122
	S+BA+20%C	68	34	0	62	89
	S+BA+25%C	51	31	0	51	56
	S+BA+35%C	48	28	0	37	42
	S+BA+50%C	85	69	0	14	16
	S+30%C	157	112	0	49	51

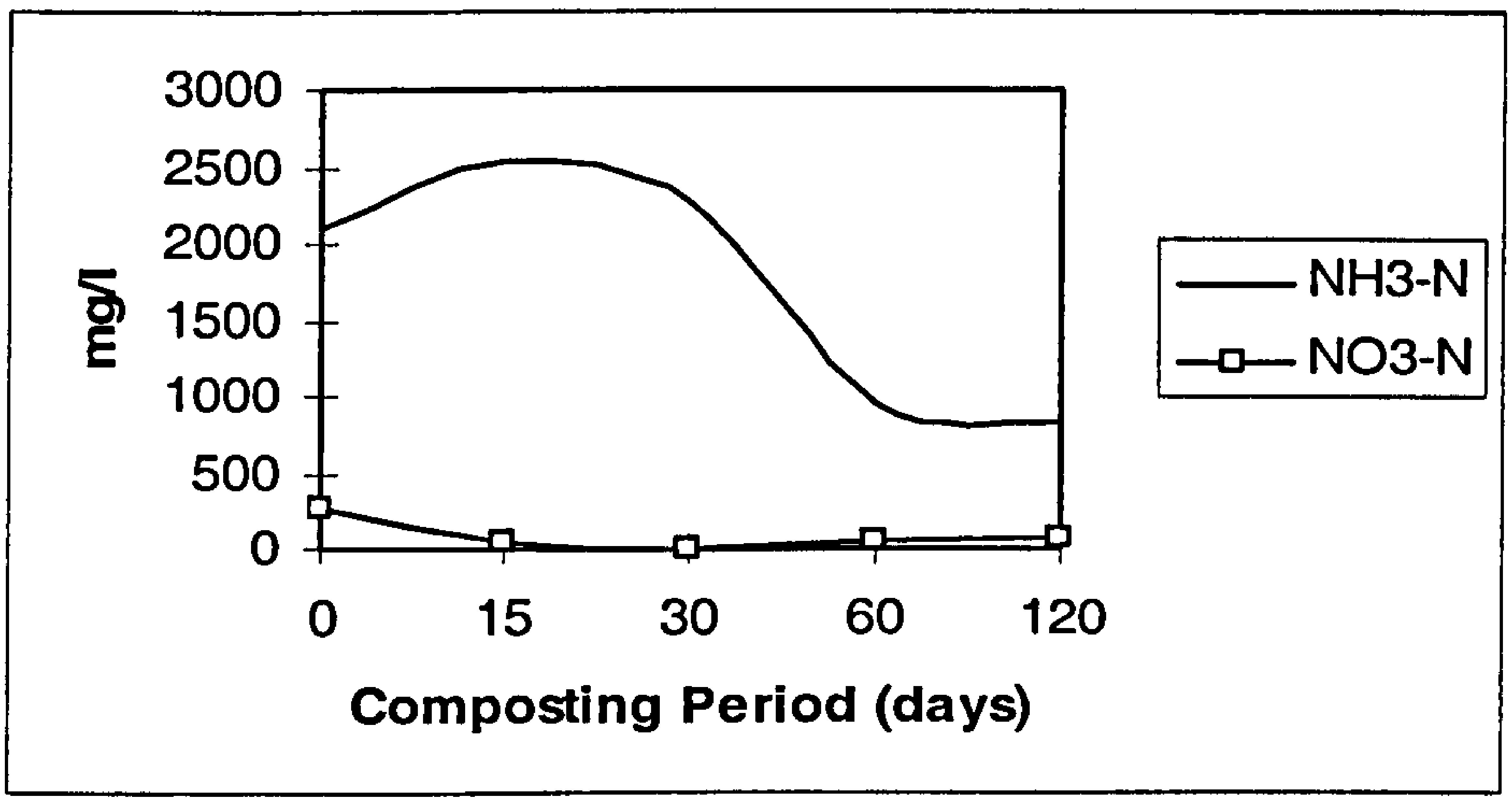

Figure 4.45. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of Windrow Pile, Phase 1

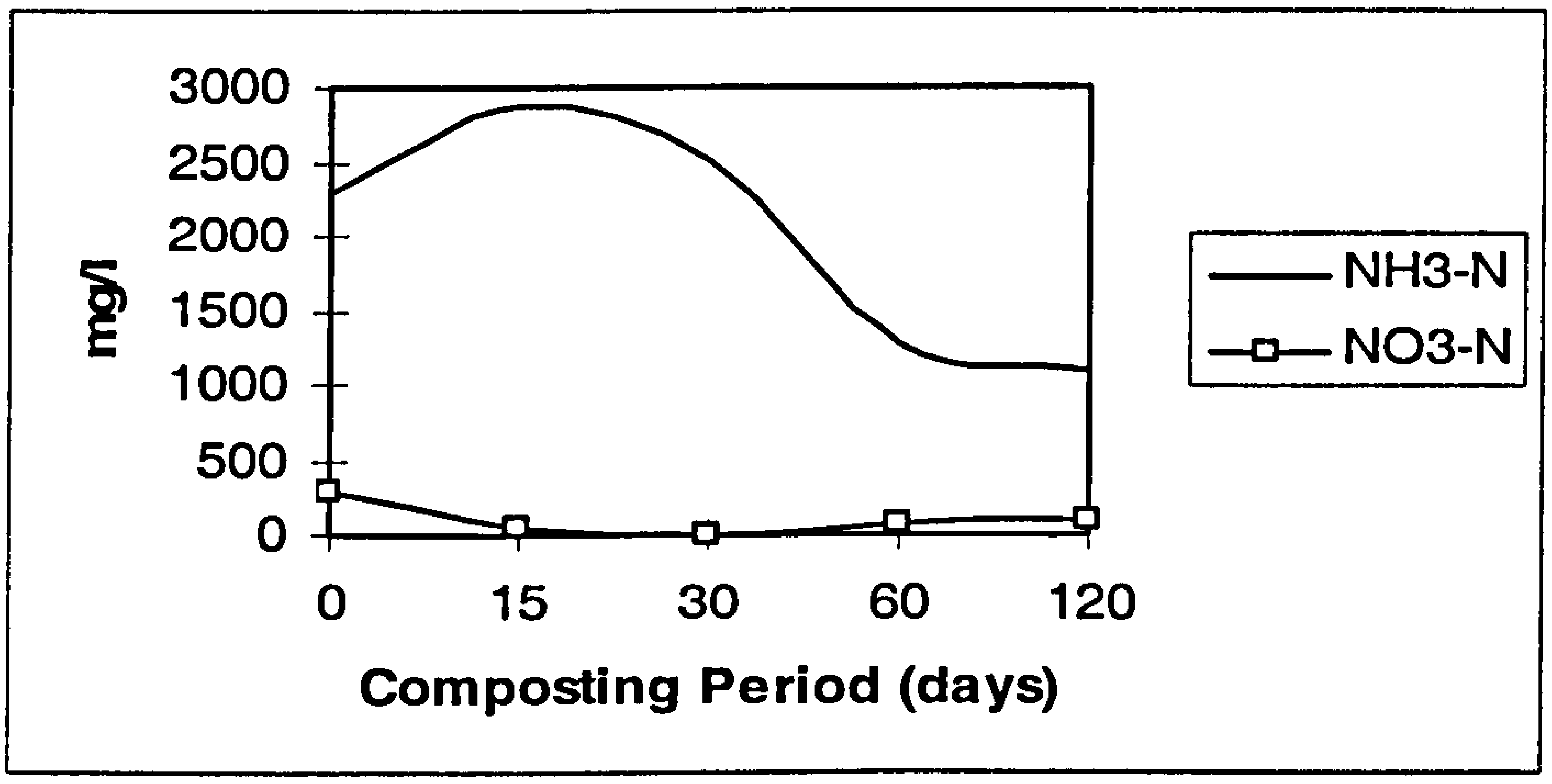

Figure 4.46. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of Passive Pile, Phase 1

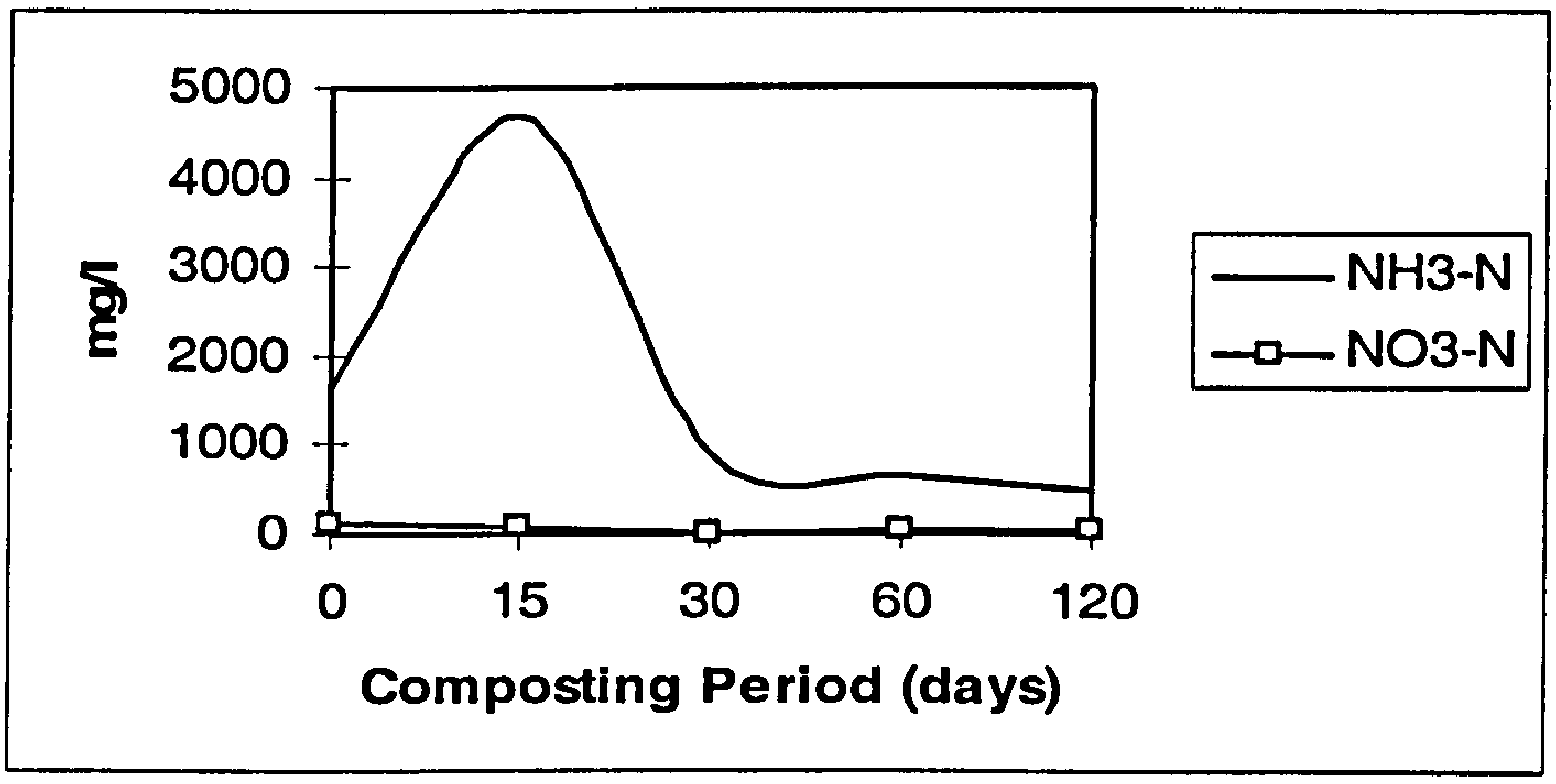

Figure 4.47. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 30% Cement Dust Pile, Phase 1

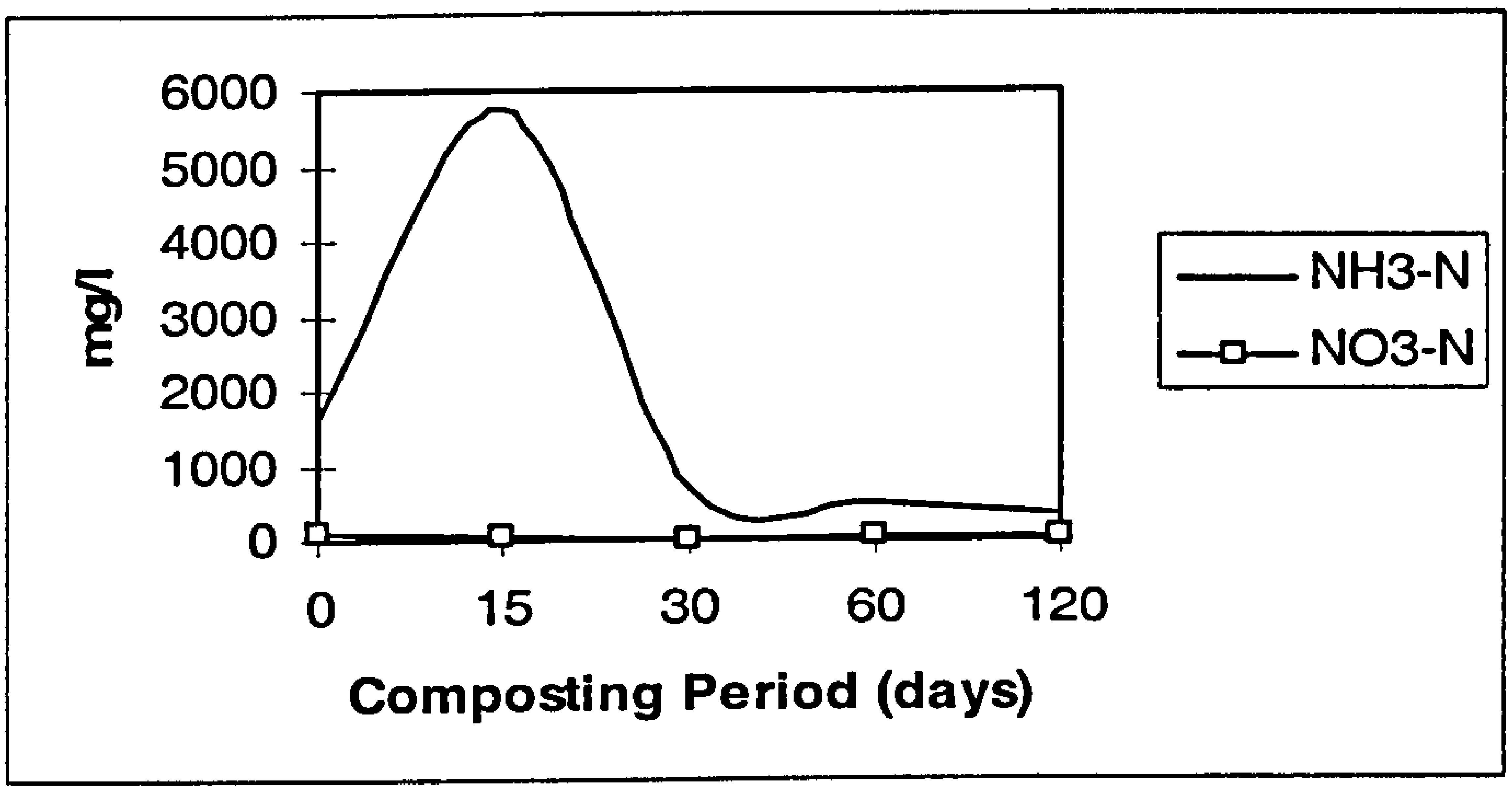

Figure 4.48. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 40% Cement Dust Pile, Phase 1

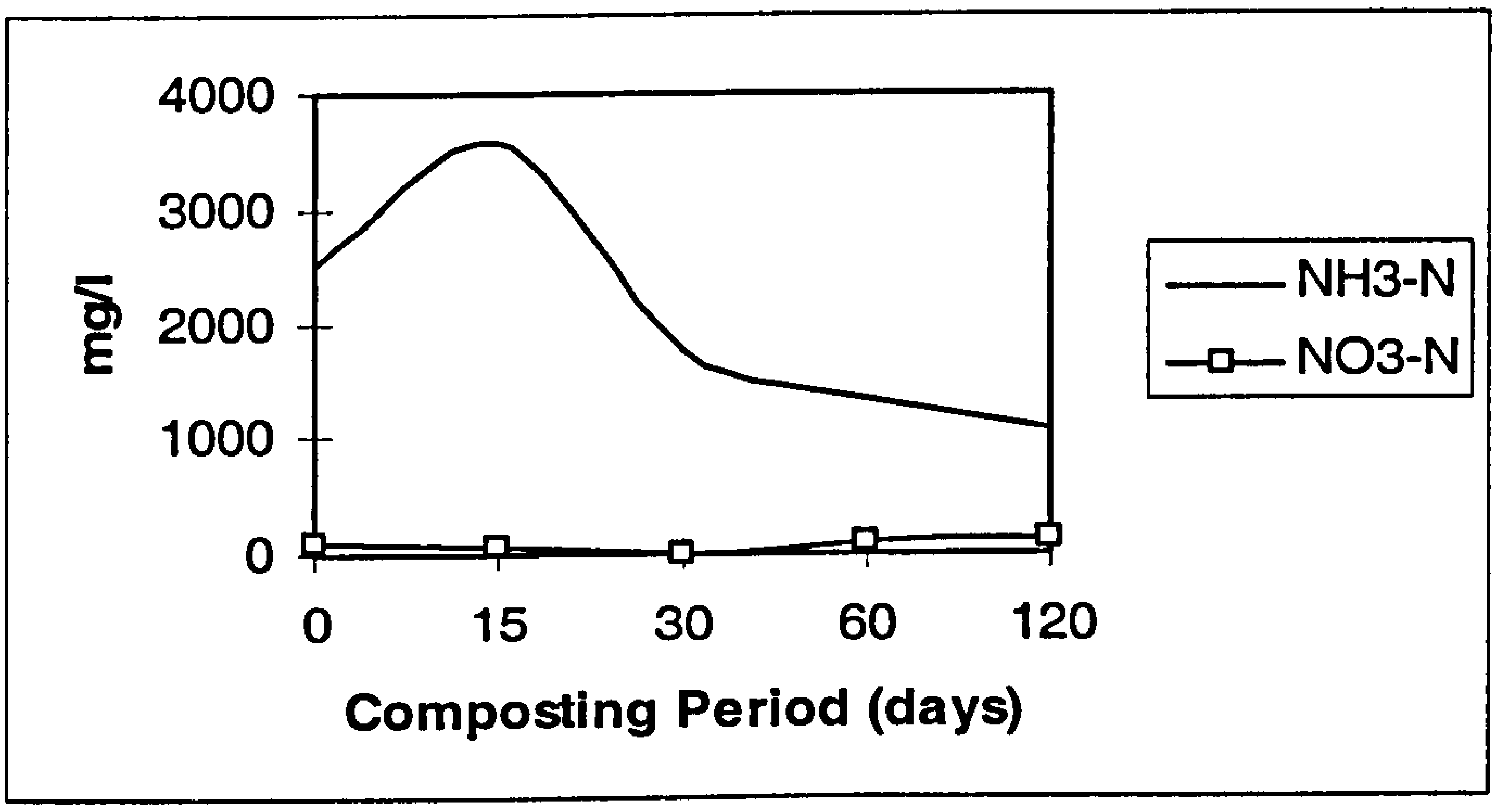

Figure 4.49. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 10% Cement Dust Pile, Phase 2

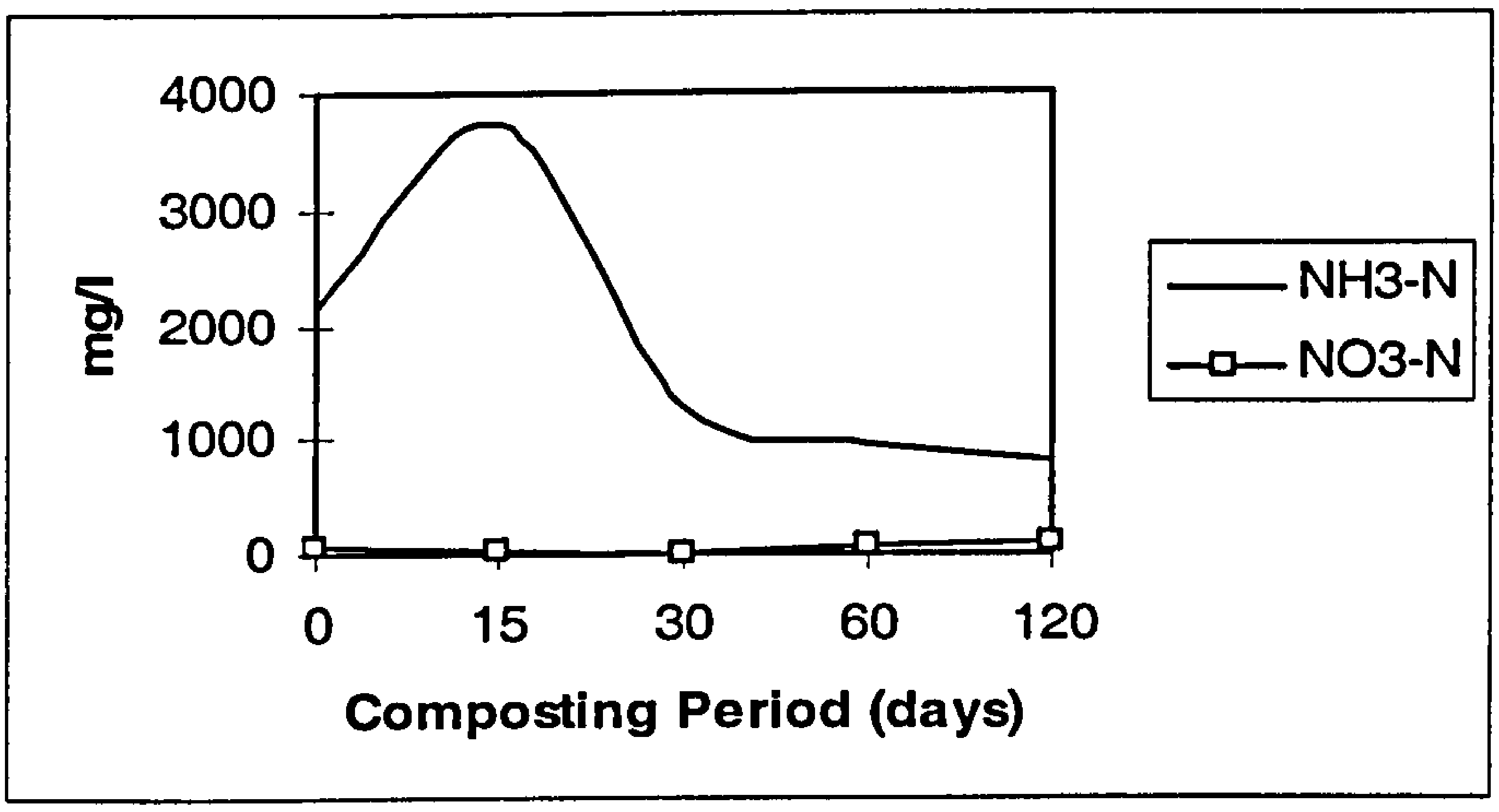

Figure 4.50. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 20% Cement Dust Pile, Phase 2

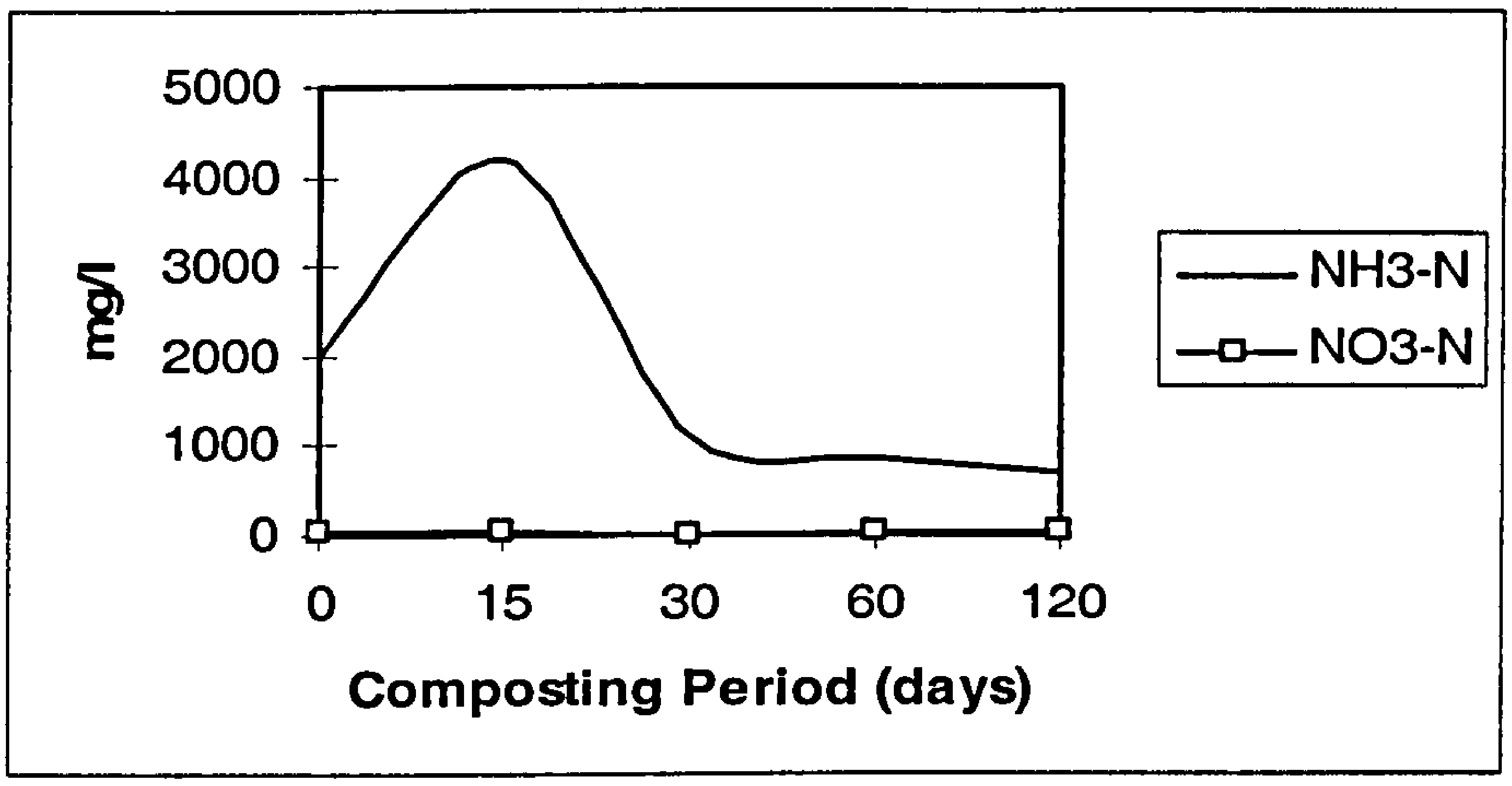

Figure 4.51. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 25% Cement Dust Pile, Phase 2

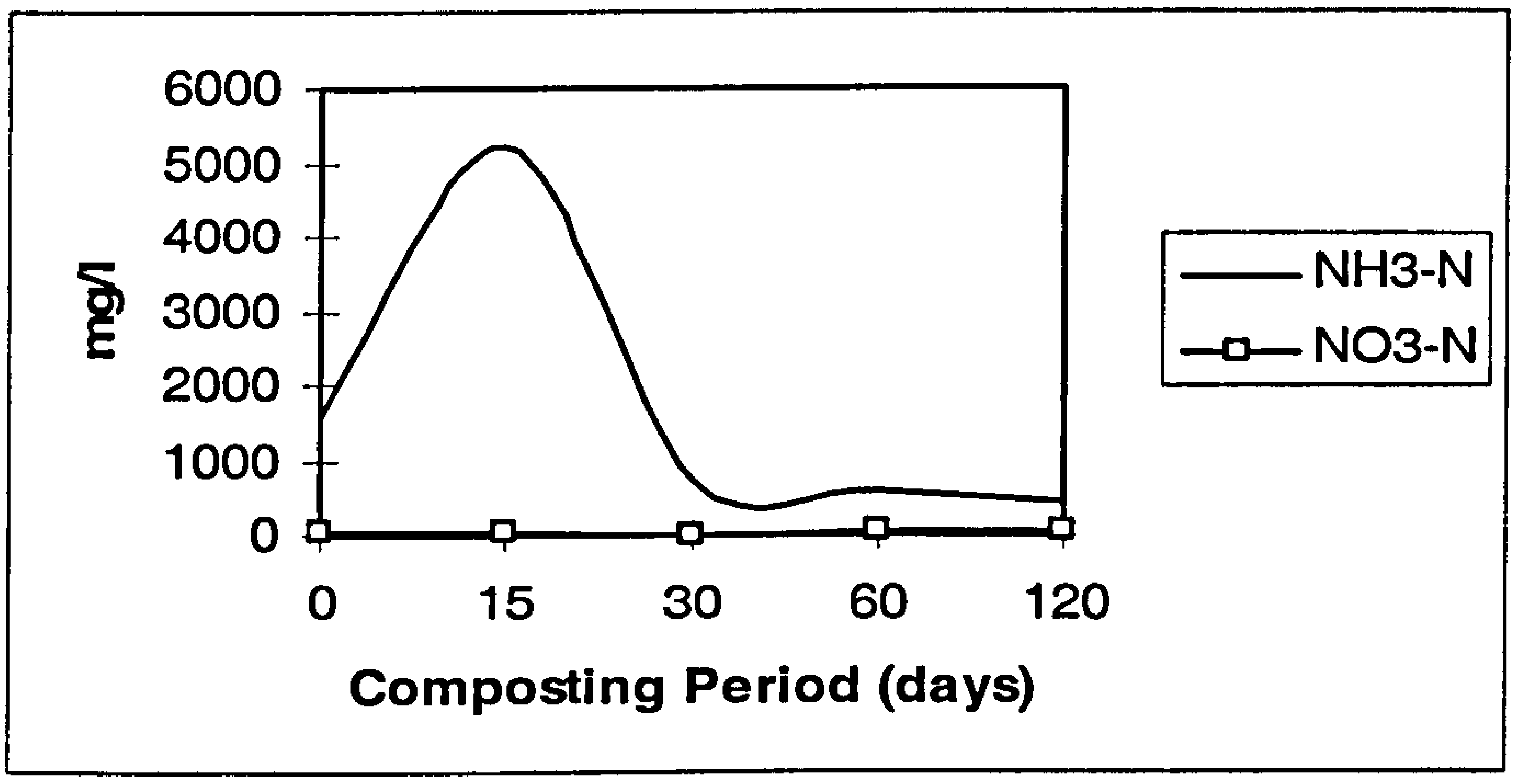

Figure 4.52. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 35% Cement Dust Pile, Phase 2

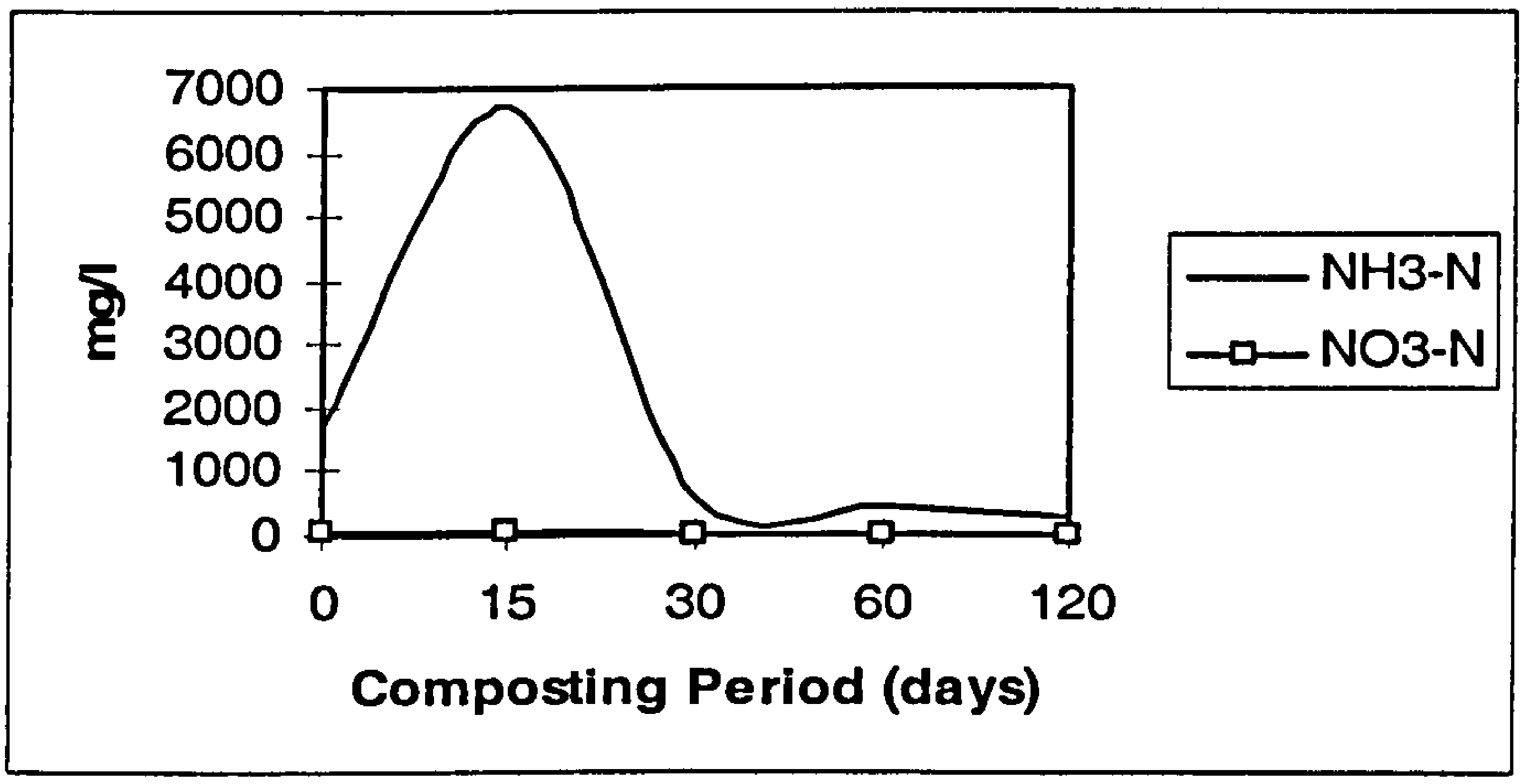

Figure 4.53. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 50% Cement Dust Pile, Phase 2

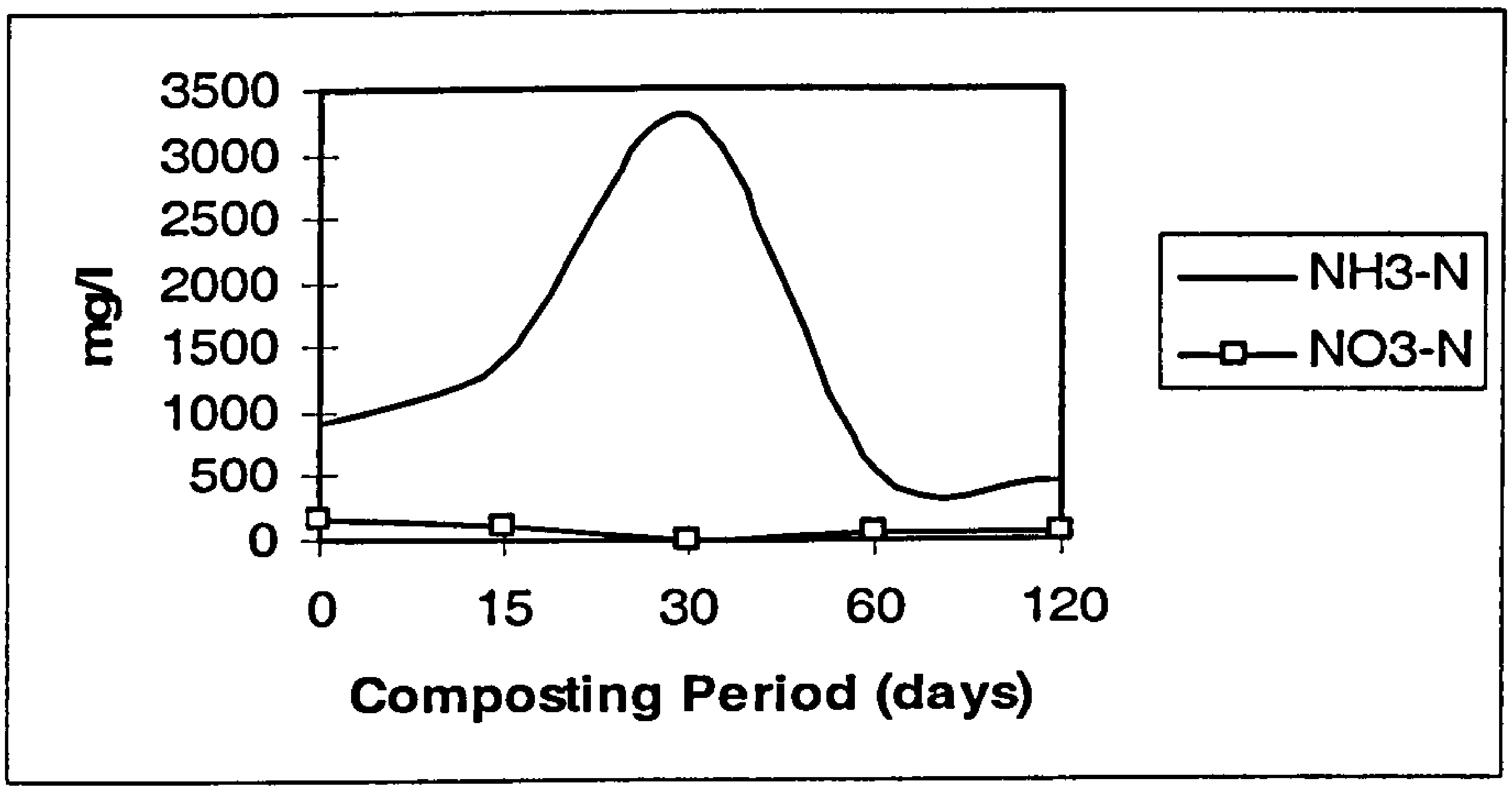

Figure 4.54. Ammoniacal Nitrogen & Nitrate Nitrogen Changes during Composting of 30% Cement Dust Pile without Bulking Agent, Phase 2

Table 4.14. Heavy Metals & Micronutrients Concentrations in Raw Sludge & Final Compost

Element	Concentration (mg/kg dry weight)*		
	Raw sludge [a]	Final compost	Concentration Limit [b]
Fe	22180	12296	
Mn	50	29	
Cu	239	137	1500
Zn	804	538	2800
Pb	789	342	300
Ni	121	81	420
Cr	134	97	1200
Hg	15	8	17

*: 1% = 10000 mg/kg = 10000 ppm.

a: Filter pressed sludge with 28.5% total solids.

b: Decree of the Minister of Housing, Utilities and Urban Communities No. 214 for year 1997.

i. Changes in macronutrients

In addition to the detection and viability studies on *Ascaris* eggs as an indicator of parasites and analysis of heavy metals content in the final compost, the concentration of macronutrients (NPK) is also important for evaluation of the composting treatment and the effect of cement dust addition. Initial samples from the filter pressed sludge (raw sewage sludge) and a composite sample from all the cement piles (windrow, passive and 30% cement dust pile without bulking agent were excluded from the composite sample) at the end of the maturation stage and after 120 days of composting were analysed for macronutrients content. **Table 4.15** shows the concentration of nitrogen (N), phosphorus (P) and potassium (K) in the raw sludge and in the final treated compost.

Table 4.15. Macronutrients Concentration in the Raw Sludge & Final Compost

Element	Concentration (%)	
	Raw sludge [a]	Final compost
N	3.449	1.497
P	1.953	2.109
K	0.251	0.294

a: Filter pressed sludge with 28.5% total solids.

The data show that after 120 days of composting, the nitrogen content had decreased, while the phosphorus and potassium had increased. The losses in nitrogen were mainly due to ammonia release, as a result of the high pH as discussed previously in section f. However, the slight increases in phosphorus and potassium are due to the decrease in organic matter during the decomposition period. In general, the values obtained for NPK after composting indicate that cement dust addition had no negative effect on the macronutrients content. However, its effect was on the nitrogen content but only when added in high concentrations (above 35% of cement dust concentration) as discussed in sections e and f.

4.2.1.4 Detection & viability of *Ascaris lumbricoides* eggs

Ascaris lumbricoides eggs were detected in the dewatered sludge before the composting process and after 15, 30, 60 & 120 days of composting. Accordingly, the compost was examined for the presence of *Ascaris lumbricoides* eggs after the end of the fermentation stage and at the end of the maturation stage. **Table 4.16** shows the data for the detection and viability of *Ascaris* eggs after 15, 30, 60, & 120 days.

Three samples were collected from the filter pressed sludge batch and all contained viable *Ascaris* eggs. As shown in Table 4.16, after 15 days of rapid composting, no *Ascaris lumbricoides* eggs have been detected for all the cement treatments. However, for the windrow and passive piles, as well as the 30% cement dust pile without bulking agent, some of the samples contained viable eggs. After 30 days of composting, *Ascaris* eggs were not detected for all the treatments, except for the windrow, passive piles and the 30% cement dust pile without bulking agent. However the passive pile samples showed nonviable *Ascaris* eggs. By the end of the fermentation stage, and after 60 days of composting, *Ascaris* eggs have been detected for the 10%, 20% and 35% cement dust piles but none of them were viable. Those samples were examined for viability using the incubation method as described in Chapter 3 (section 3.2.2). The eggs showed no sign of development throughout the 30 days period, and were considered non-viable. At the end of the maturation stage, no *Ascaris* eggs were detected for all the cement dust piles with bulking agents, as shown in Table 4.16.

The results obtained were in accordance with many investigators. Bruce et al. (1982) proved that thermophilic temperatures produced complete inhibition of parasite egg development. He added that the percent of damaged eggs increased in relation to increased temperature and to the duration of exposure. Remiers et al. (1986) confirmed these findings in a study on the effectiveness of waste treatment processes to inactivate parasites, in order to obtain sludge without restrictions on its subsequent use. He stated that thermophilic composting was effective in inactivation of parasites. This study also confirmed these findings.

Regarding the cement dust piles with bulking agents, *Ascaris* eggs were not detected in most of the samples collected from all the different piles. The effect of high pH and temperature for long periods of time would inactivate *Ascaris* eggs and even cause disintegration of the eggs, that it's identification would be very difficult. In addition, according to Amer (1993), Counts et al. (1975) and Jeffrey et al. (1990) stated that the release of ammonia may have a great effect in the disinfection process.

4.2.1.5. Statistical analysis

The effects of time, temperature, pH and CO_2 on the viability of *Ascaris* eggs in the compost process were statistically analysed using binary logistic regression. MINITAB package (version 12) was used for the analysis, however, the statistical analysis led to no significant new findings.

Table 4.16. *Ascaris lumbricoides* Eggs Detection and Viability during Composting for Phases 1 & 2.

Phase	Treatment	Detection and Viability of *Ascaris* Eggs during Composting Periods (days)											
		Fermentation stage									Maturation stage		
		15			30			60			120		
		Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
Phase 1	S+BA (W)	+	-	-	-	+	+	-	-	-	ND	-	-
	S+BA (P)	-	-	+	-	-	-	ND	ND	ND	-	ND	ND
	S+BA+30%C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	S+BA+40%C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phase 2	S+BA+10%C	ND	ND	ND	ND	ND	ND	ND	-	ND	ND	ND	ND
	S+BA+20%C	ND	ND	ND	ND	ND	ND	-	ND	ND	ND	ND	ND
	S+BA+25%C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	S+BA+35%C	ND	ND	ND	ND	ND	ND	ND	-	ND	ND	ND	ND
	S+BA+50%C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	S+30%C	+	+	+	+	+	+	+	-	-	+	-	-

+: Viable eggs.

-: Non-viable eggs.

ND: Not detected

CHAPTER FIVE: CONCLUSIONS & RECOMMENDATIONS

5.1. Summary of Studies

The objectives of this research were based on the health problems associated with the application of unsanitised sludge onto agricultural land under Egyptian conditions, as well as the gaps in knowledge identified by the literature review. Two different types of sludges from two popular sewage treatment processes were used in this study, namely: anaerobic pond sludge from a wastewater stabilisation pond system at Mit Mazah, Daqahlia Governorate, and filter pressed primary sludge from a primary sewage treatment plant at Alexandria. The sludge treatment processes studied were chosen primarily to be simple and cheap, in order to suit urban as well as rural areas, from which the main health hazard emerges. Under Egyptian conditions, *Ascaris* eggs represent the main health concern in sludge application to land and the effects of sand drying beds and passive composting system of the sludges (with agricultural wastes and cement dust amendments) were selected for study, particularly in respect of the inactivation of *Ascaris* eggs.

The field studies have produced new information concerning:

- Characterisation (physicochemical and *Ascaris* content) and assessment of the accumulation pattern and quantity of anaerobic pond sludge. This information will be helpful in assessing the suitability of anaerobic pond sludge for disposal to land, without further treatment.
- The effects of sand drying bed dewatering of anaerobic pond sludge on the total solids content and lethal desiccation levels for *Ascaris* eggs.
- The effects of a passive composting system (an alternative to the expensive aerated static pile system) of filter pressed primary sludge with agricultural wastes on the final compost quality and the inactivation of *Ascaris* eggs.
- The effect of cement dust, as an amendment within the composted raw materials, on the decomposition process and inactivation of *Ascaris* eggs.

The conclusions of the study are presented individually for experimental programs I and II. Experimental program I was concerned with the anaerobic stabilisation pond sludge characterisation, accumulation and quantity, as well as a study of its application onto sand drying beds during the winter (two trials) and summer (one trial) seasons. Each trial lasted for a period of two months and the subsequent effect on *Ascaris* eggs survival was assessed. Experimental program II was concerned with the characterisation and analyses of filter pressed primary sludge and determination of the effects of using a passive composting system on the sludge, with different agricultural wastes (fennel and basil) and cement kiln dust concentrations, in respect of the decomposition process and survival of *Ascaris* eggs. In addition, passive and windrow composting systems were compared with regard to the decomposition process and effect on *Ascaris* survival. The suitability of mixing the primary sludge with cement dust only, without the need for a bulking agent, was also studied for its effect on the decomposition process and the survival of *Ascaris* eggs. The composting study was carried out for four months, two months each for the fermentation and maturation stages.

5.1.1. Experimental Program I

5.1.1.1. Mit Mazah anaerobic pond Sludge

- The Cairo Sludge Disposal study, which was carried out by the UK's Water Research Centre over 45 months in the period 1995 to 1999, concluded that, under Egyptian conditions, treatment processes for sludge must be designed to eliminate *Ascaris* eggs. In addition, it was found that the current concentrations of potentially toxic elements (PTE) in the Egyptian sludges tested were within the national standards and similar to those levels found in Europe.
- Raw wastewater entering Mit Mazah wastewater stabilisation ponds (WSP) is classified as very strong, compared with reported strength classifications in the literature. Average BOD_5, COD and total dissolved solids (TDS) values for Mit Mazah raw wastewater were 887, 1537 and 1067 mg/l, respectively. From the analyses, the iron content in the wastewater was high, especially for a village having no industrial waste discharges. The possible cause of the high iron content could be the water source supplied to the village. Regarding the parasitological

analysis of the raw wastewater, *Ascaris* eggs were detected in the samples and were found to be viable.

- Anaerobic ponds have the ability to store sludge for long periods and, in the case of the Mit Mazah anaerobic pond, a sludge volume of about 2430 m^3 (sludge occupied about 78% of the total volume of the pond) had accumulated from 1992 to 1997. The maximum depth of sludge recorded was 3.5 metres at the side wall on the inlet side. The annual sludge accumulation rate, estimated from the mean sludge depth (3.1 metres) and the accumulation period was 44 cm depth/year.
- The sludge from the anaerobic pond was black in colour, granular in texture, well compacted and had no objectionable odour. Samples collected from the anaerobic pond sludge at the inlet side, middle and outlet side of the pond showed very similar concentrations, indicating the homogeneity of sludge across the pond. All the sludge samples had a neutral pH, ranging from 7.2 to 7.4. The average dry solids content of the sludge samples was approximately 18%, ranging from 16% to 19.5%. The total volatile solids content (TVS) averaged approximately 47% of the total solids. With regard to macronutrients, the nitrogen, phosphorus and potassium contents of the total solids content in the sludge samples averaged 4.0%, 1.5% and 0.275%, respectively. From these analyses and by comparison with a typical digested sludge physicochemical analysis, it is very clear that the Mit Mazah sludge was very well digested and compacted, due to the nature of the operation of the stabilisation pond. Regarding the *Ascaris* content in the anaerobic pond sludge, no viable *Ascaris* eggs were detected in any of the samples collected. This could be expected, considering the age of sludge and the extensive anaerobic digestion process it had gone through for more than 6 years. This represents one of the main benefits of the stabilisation pond treatment process.
- From the characterisation and assessment of the anaerobic pond sludge from Mit Mazah wastewater stabilisation pond system, it is concluded that the sludge is safe to be applied onto agricultural land, after an appropriate dewatering process.

5.1.1.2. Sludge drying bed applications

- Sludge drying beds are the simplest and cheapest form of dewatering process to reduce sewage sludge moisture content to levels which are considered to be lethal to *Ascaris* eggs. The results from the literature, confirmed by the present study, stress the fact that drying beds are suitable for tropical (hot climate) countries, due to the favourable weather conditions for the air drying process.
- Regardless of the depth of sludge layer over the range 15 to 25 cm, it was found that the depth of the underlying sand layer had a major effect on the removal of water through drainage from the drying bed. Thinner sand layers, of the order of 15 cm, eased the drainage process and it was observed during the winter trials that most of the water was removed by drainage under such conditions.
- *Ascaris vitilorum* eggs (cattle ascarid) seeded to the anaerobic pond sludge were inactivated within 30 days by sand bed drying during the winter season (October and November) in the top layers of the drying beds, where the solids content averaged approximately 85%. However, at the end of the two month drying period, the middle and bottom layers contained an average solids content of 72 to 77% and viable *Ascaris* eggs were detected.
- During the second sludge application in the winter season (December and January), unfavourable weather conditions prevailed. By the end of the 60 days drying period, the total solids content of sludge on the drying beds averaged 54% in the top layers. The middle and bottom layers of sludge had an average total solids content of 49% and 44%, respectively. Throughout this winter drying period, all sludge samples collected from all depths were positive for viable *Ascaris* eggs in the sludge.
- During the summer season, samples collected from the drying beds after 17 days of drying did not contain viable *Ascaris* eggs in the top layers, where the solids content ranged from 74% to 63%. After one month of summer drying, no viable *Ascaris* eggs were detected throughout the entire depth of sludge on the drying beds. The lowest solids content recorded was approximately 80% for the bottom layer of sludge on one drying bed.

- From this study, as well as from previous research, it appears that sludge moisture content is one of several variables, along with the nature of sludge (raw or digested), solar radiation, temperature and time, which can influence the destruction of *Ascaris* eggs in sludge on drying beds. Even though Egypt is blessed with favourable weather conditions for the use of outdoor dewatering processes, such as drying beds, during the wet season (December and January) drying beds were not effective in destroying *Ascaris* eggs. During the summer season, parasites in sludge can be inactivated much more rapidly, compared with the winter season, as a result of the high sludge temperature, and quick moisture removal.
- It was clear, during the wet season, that drainage was the main mechanism by which loss of moisture was achieved. This could be enhanced by applying sludge onto thinner sand layers (15 cm range), which facilitated the drainage process. However, during the dry season in Egypt, evaporation was found to be the main mechanism by which removal of moisture was achieved.

5.1.2. Experimental Program II

5.1.2.1. Primary sludge and compost materials

- From the 20 tons of belt filter pressed sludge used for the pilot scale composting work, a representative sample of a mixture of random samples was taken for full analysis of physicochemical characteristics and *Ascaris* content. The physicochemical analyses of the filter pressed primary sludge showed that the sludge was undigested and the presence of viable *Ascaris* eggs was confirmed. The composite sample analysed showed pH, moisture content, BOD_5, COD and organic matter content of 6.09, 20.413%, 32766 mg/kg, 89574 mg/kg, and 75.96%, respectively.
- Agricultural wastes from a fennel and basil production factory were used as bulking agents in the composting process. The physicochemical analyses of the fennel and basil wastes showed their potential for such use, serving the purpose of a bulking material (reduce moisture content, provide structure, texture and porosity, and adequate C/N ratio). The fennel and basil wastes had moisture contents and C/N ratios of 6.6% and 7.4%, and 50.6:1 and 45:1, respectively.

- Cement dust by-pass from Helwan cement factory in Cairo, which is disposed of by dumping into the desert, was used as an additive to sludge in some of the composting studies. The cement dust was characterised by high pH (12.49), low moisture content (0.02%) and NPK contents at 0.0045%, 0.0033% and 0.1227%, respectively.

5.1.2.2. Composting process

- By comparing passive and windrow pile composting (control piles without cement dust addition), it has been proved that the passive technology is much more efficient in maintaining regular high temperatures in the composting sludge for a much longer duration (additional 10 days), due to the favourable aerobic conditions maintained.
- Passive technology was very efficient in naturally controlling the internal temperature of composting piles for all the sludge/cement dust piles with bulking agents. Excessive heat was released to the atmosphere through the chimney effect created by the circulation of air through the perforated pipes and upwards into the pile. Internal temperatures, even for the highest cement dust concentration piles, did not exceed 73°C.
- At the end of the fermentation stage of composting, it was essential to turn the piles in order to make sure that the microorganisms were in contact with the relatively undigested parts of the piles.
- CO_2 evolution data proved to be a much more useful measure of composting activity and the decomposition process, rather than the temperature readings in the case of sludge/cement dust piles. As long as the organic matter was being consumed, O_2 was consumed and CO_2 was released. On the other hand, increase in temperature within the cement dust piles during the initial stages was the result of the exothermic reactions occurring as a result of cement dust addition and, accordingly, the temperature within the piles increased within several hours after forming the piles, not necessarily due to the microbial activity in decomposing the organic matter.

- From the results of the cement dust composting piles, it can be concluded that more than 35% concentration of cement dust was unfavourable for the decomposition process. No biological activity took place during the first 4 and 7 days of the composting process, in the 35% to 50% cement dust piles, respectively. In general during the two months fermentation stage, very limited biological activity took place within the 40% and 50% cement dust piles, as a result of the high pH and high temperature levels attained due to the effect of cement dust and dehydration of the organic matter. The decomposition process started in the maturation stage, during which the compost environment was much more favourable (low pH, adequate moisture content and temperature elevation due to the microbial activity). In spite of the delay in start-up of the decomposition process, by the end of the composting process, the losses in organic matter and the final C/N ratio of the 40% and 50% cement dust piles were within the accepted range for mature and stabilised compost. The total loss of organic matter was approximately 54% for both piles, and the final C/N ratio was 12.8:1 and 14.6:1 for the 40% and 50% cement dust piles, respectively.
- Piles with less than 30% cement dust concentration had a loss of about 10% total nitrogen. However, piles with more than 30% cement dust concentration lost relatively high nitrogen content (compared to passive and lower cement dust concentration piles), from 24% to 41%, for the 35% to 50% cement dust piles, respectively. The high losses of nitrogen resulted from the release of ammonia, encouraged by the high pH, high temperature, as well as by leaching after the frequent moistening of the piles. It has been noted that after 15 days of composting, a significantly high amount of ammoniacal nitrogen was released, ranging between 5243 and 6729 mg/l for the 35% to 50% cement dust piles, respectively. By the end of the composting process, the residual ammoniacal nitrogen content within the 35% to 50% cement dust piles ranged between 429mg/l and 261 mg/l, compared to 1109 mg/l and 837 mg/l for passive and windrow piles (control piles), respectively. This proves the fact that the high pH favours the gaseous ammonia form, which was released to the environment, and thus the nitrogen content decreased significantly.
- The 30% cement dust pile without bulking agent did not function properly due to the lack of air voids, very high moisture content and prevailing anaerobic

conditions. This was indicated by the ambient internal temperatures during the fermentation stage, as well as the lack of CO_2 evolution within the pile. However, the decomposition process started during the maturation stage after the excess water was removed and aerobic conditions prevailed.

- The stability and maturity of the compost is not enough as a measure of suitability for use on land; nutrient content is another important factor to be considered. The concentrations of the macronutrients (NPK) in the final treated compost was compared with those in the raw sludge, in order to study the effect of cement dust addition. The composite sample from all the sludge/cement dust piles with bulking agent indicated a decrease in nitrogen content (3.449% in the raw sludge compared with 1.497% in the compost sample), increase in phosphorus content (1.953% to 2.109%) and increase in potassium content (0.251% to 0.294%). In general, the values obtained for NPK after the composting process indicate that cement dust addition had no negative effect on the macronutrients content. However, as discussed previously, more than 30% cement dust concentration caused a significant decrease in nitrogen content.
- Initial samples from the filter pressed primary sludge (raw sewage sludge) and a composite sample from all the sludge/cement dust piles with bulking agents showed that the heavy metals content in the final treated compost had been reduced significantly by the end of the maturation stage and after 120 days. This was due to the diluting effect of the bulking agent and, possibly, due to the cement dust addition (increase in pH), which results in a significant reduction in heavy metals' solubility at high pH. The final compost was within the Egyptian regulatory standards, except for lead which in the primary sludge exceeded the limits, by far.
- From a hygienic point of view, the passive composting system proved to be much more effective in inactivating *Ascaris* eggs, compared to the windrow pile system. Non-viable *Ascaris* eggs were not detected after 30 days of composting using the passive technology, compared with 60 days of composting for the windrow pile.
- All sludge/cement dust piles with bulking agent proved to be very effective in inactivating *Ascaris* eggs after only 15 days of composting, mainly by the influence of high pH, high temperature levels for long periods and, maybe, due to high release of ammonia gas.

- The 30% cement dust pile without bulking agent was found to be unsuccessful in inactivating *Ascaris* eggs. Viable *Ascaris* eggs were detected throughout the 120 days of composting. This could be expected, due to the unsuccessful operation of the pile (no biological activity and low temperatures).
- Considering all the different parameters for evaluating a treated compost, including stability, maturity, nutrient content, heavy metals content and viable *Ascaris* eggs content, for the sludge/cement dust piles with bulking agent it can be concluded that more than 30% cement dust concentration in composting sludge is unfavourable, giving rise to a relatively high loss of nitrogen content. More than 35% cement dust concentration is unfavourable as a result of the delay of the decomposition process, the elongation of the composting period and the high loss of nitrogen content.
- Passive composting technology preserves the nitrogen content through the naturally controlled internal temperature, less turning and lower loss of moisture. By the end of the composting process, the total nitrogen content for the passive and windrow piles was a gain of 17.5% and a loss of 0.7%, respectively, while the ammoniacal nitrogen content within the piles was 1109 mg/l and 837, respectively.

In conclusion, sand bed drying is considered to be a suitable process for dewatering of anaerobic stabilisation pond sludge in Egypt, inactivating *Ascaris* eggs within one month during the summer season. Extended periods between anaerobic stabilisation pond desludging, of the order of 6 years, will result in a dewatered sludge which will be suitable for direct application to agricultural land. Passive composting is an appropriate technique for preparation of Egyptian filter pressed primary sludge for safe application to agricultural land. Cement dust additions of less than 30% concentration, in the composting sludge mixture undergoing passive composting produces sanitised and mature compost. The potential for co-disposal of agricultural wastes and cement kiln dust as bulking agents and additive, respectively, with sewage sludge in the production of compost, is very promising to produce a safe and beneficial outcome to the community.

5.2. Recommendations

The results of this two years study on the effect of drying beds and passive composting technology on sewage sludge, with cement dust and other agricultural wastes as bulking agents/additions, in terms of the decomposition process, compost quality and survival of *Ascaris* eggs, indicated that further information should be obtained by further research. The specific areas recommended for additional research are as follows:

- Information is needed on the optimum storage time of sludge in anaerobic waste stabilisation ponds, for ensuring the thorough digestion of sludge and inactivation of parasites.

- Information is needed on the effect of CO_2 evolution and ammonia production on the viability of *Ascaris* eggs during passive composting.

- The effect of the different agricultural and industrial wastes (such as cement dust, lime, etc.) used as bulking agents should be studied at various concentrations for their effect on heavy metals contained in sewage sludge.

- Models need to be developed for the effect of the different cement dust and other wastes concentrations on the loss of nitrogen content (calculated on the basis of organic matter losses, weight and volume reductions, C/N ratio, etc.).

- Further information is required on passive composting technology using cement dust and other wastes additions during winter, since the problem of high moisture loss during the summer season would not be encountered.

- A better understanding is needed of the effect of the different cement dust and other waste additive concentrations on the reduction of the number of viable *Ascaris* eggs with time using the passive composting system and other systems.

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APPENDIX 4.1

Data collected during the sand drying bed applications

First Trial during October and November

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
1	29	24	24	23	34	30	30	31
2	28	23	23	23	34	30	30	30
3	25	20	20	19	32	29	29	29
4	27	22	22	22	33	28	29	29
5	26	20	21	20	32	28	28	29
6	26	21	21	20	33	29	29	28
7	28	24	23	23	34	30	30	30
8	29	24	24	23	35	30	29	30
9	29	24	24	23	33	29	29	29
10	27	22	22	21	33	29	29	33
11	26	21	21	21	32	28	30	29
12	26	21	21	20	35	30	30	29
13	26	21	21	20	32	29	29	29
14	28	22	23	23	34	30	30	30
15	25	20	20	19	35	28	28	28
16	28	23	23	22	34	26	26	26
17	25	21	20	20	31	26	26	26
18	25	20	20	19	31	26	27	27
19	24	19	19	18	30	25	27	26

First Trial during October and November (continued)

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
20	26	21	21	19	30	28	29	28
21	25	20	20	19	31	28	29	29
22	25	20	20	19	31	27	28	28
23	22	17	17	19	29	26	26	26
24	25	20	20	19	31	27	26	27
25	24	19	19	20	30	25	25	26
26	25	20	20	19	31	27	26	27
27	26	21	21	20	30	26	25	26
28	24	19	19	20	30	26	25	26
29	25	20	20	19	31	27	27	27
30	24	19	19	19	30	26	25	26
31	23	17	17	17	28	24	23	24
32	21	16	16	15	27	23	22	23
33	19	14	14	13	25	21	21	21
34	20	15	15	14	26	22	21	22
35	21	16	16	15	25	21	20	21
36	21	16	16	15	27	23	21	23
37	19	14	14	13	26	22	21	22
38	21	16	16	15	27	23	22	23
39	22	17	16	15	26	21	21	22
40	19	14	14	13	25	21	20	21
41	20	15	15	14	26	22	21	22
42	20	15	15	14	28	24	24	24

First Trial during October and November (continued)

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
43	21	16	15	15	27	23	22	23
44	23	18	18	17	27	23	22	23
45	20	15	15	14	26	22	21	22
46	21	16	16	15	27	23	22	23
47	19	14	14	13	25	21	20	21
48	18	13	13	12	24	20	20	20
49	21	16	16	15	27	23	22	23
50	22	17	17	16	28	24	19	24
51	21	16	16	15	27	23	22	23
52	20	15	15	13	26	22	21	22
53	21	16	16	15	27	23	22	23
54	19	14	14	13	25	21	20	21
55	21	16	16	15	27	23	22	23
56	20	15	15	14	26	22	21	20
57	20	15	15	14	25	21	21	21
58	20	15	15	14	27	23	22	23
59	18	14	13	12	25	21	20	21
60	21	16	16	15	26	22	21	22

Second Trial during December and January

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
1	21	14	16	15	26	21	20	21
2	19	15	14	14	25	20	19	20
3	20	15	15	15	27	22	21	22
4	19	14	14	14	25	20	19	20
5	18	13	13	12	24	19	18	19
6	15	10	10	10	20	15	14	15
7	18	13	13	13	24	19	18	19
8	16	11	10	11	20	16	14	15
9	17	12	12	12	23	18	17	18
10	15	10	12	10	22	17	16	17
11	14	9	9	9	20	15	14	15
12	15	10	11	10	21	17	15	16
13	12	7	9	7	19	15	13	14
14	15	10	10	11	21	17	15	16
15	14	9	9	8	19	15	13	14
16	18	13	13	12	24	20	18	19
17	19	14	14	13	25	21	19	20
18	17	12	12	11	24	20	18	19
19	15	10	10	9	21	17	15	16

Second Trial during December and January (continued)

Days	Air temperature (^oC) at 10 a.m.	Sludge temperature (^oC) at 10 a.m.			Air temperature (^oC) at 2 p.m.	Sludge temperature (^oC) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
20	15	10	10	9	20	16	14	15
21	12	7	7	6	18	14	12	13
22	12	7	7	6	17	13	11	12
23	8	4	3	3	14	10	8	9
24	12	8	7	8	18	14	12	13
25	11	7	6	6	17	13	11	12
26	9	5	4	4	16	12	10	11
27	12	8	7	7	18	13	12	13
28	15	11	10	10	21	16	15	16
29	15	11	10	10	23	18	17	18
30	15	11	10	10	21	16	15	16
31	14	10	9	9	20	15	14	15
32	18	14	13	13	24	19	18	19
33	17	13	12	12	23	18	17	18
34	15	11	10	10	20	15	14	15
35	13	9	8	8	19	14	13	14
36	15	11	10	10	19	14	13	14
37	17	13	12	12	23	18	17	18
38	15	11	10	10	21	16	15	16
39	13	8	8	8	20	15	14	15
40	15	10	10	10	21	16	15	16
41	17	12	12	12	23	18	17	19
42	15	10	10	10	21	16	15	16

Second Trial during December and January (continued)

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
43	14	9	9	9	20	15	14	15
44	17	12	12	12	24	19	18	20
45	14	9	9	9	20	15	14	16
46	15	10	10	10	21	16	15	17
47	14	9	9	9	20	15	14	16
48	13	8	9	8	18	13	12	14
49	14	9	10	9	20	15	14	16
50	12	7	8	7	17	12	11	13
51	13	8	9	8	19	14	14	15
52	13	8	9	8	19	14	13	14
53	15	10	11	10	21	16	15	16
54	14	9	10	9	18	13	12	13
55	12	7	8	7	18	13	13	13
56	12	7	8	7	17	12	12	12
57	13	8	9	8	19	14	14	15
58	12	7	8	7	18	13	13	14
59	10	5	6	5	19	14	14	15
60	12	7	8	7	18	13	13	14

Summer trial during July and August

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
1	24	23	22	22	32	34	34	36
2	27	26	26	25	33	36	35	35
3	26	24	24	25	34	36	36	36
4	27	26	25	25	35	37	37	37
5	33	32	31	31	39	42	41	41
6	30	29	28	29	38	41	41	40
7	29	28	27	27	37	40	39	39
8	32	30	30	30	38	41	40	40
9	27	25	26	25	35	38	37	37
10	28	26	27	27	36	39	39	38
11	29	27	28	27	35	37	38	39
12	28	26	27	26	36	38	39	40
13	30	29	29	29	38	40	41	42
14	30	29	29	29	37	39	40	41
15	28	27	26	26	35	37	38	39
16	31	30	29	29	39	41	42	43
17	32	30	30	30	38	40	41	42
18	30	28	28	28	37	39	40	39
19	32	30	30	31	38	40	40	40

Summer trial during July and August (continued)

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
20	27	25	25	26	35	37	37	37
21	28	26	26	26	36	38	38	38
22	29	27	28	27	35	38	37	37
23	30	28	29	28	38	41	40	42
24	30	29	29	28	37	40	39	41
25	31	30	30	29	39	42	42	43
26	31	30	29	29	38	41	41	42
27	34	33	32	33	40	43	43	44
28	32	31	30	30	39	41	41	43
29	32	31	30	30	40	42	42	44
30	34	33	32	32	41	43	43	45
31	35	34	33	34	42	44	44	46
32	32	31	30	30	40	42	42	44
33	32	31	30	30	38	40	40	42
34	31	30	29	29	39	41	41	43
35	33	32	31	31	41	43	43	43
36	36	35	34	34	43	45	45	45
37	34	33	32	33	42	44	44	44
38	36	35	34	35	43	45	45	45
39	34	33	32	33	42	45	44	44
40	36	35	34	35	43	46	46	45
41	35	34	33	34	41	44	44	45
42	35	34	33	33	42	45	45	46

Summer trial during July and August (continued)

Days	Air temperature (°C) at 10 a.m.	Sludge temperature (°C) at 10 a.m.			Air temperature (°C) at 2 p.m.	Sludge temperature (°C) at 2 p.m.		
		D.B. 1	D.B. 2	D.B. 3		D.B. 1	D.B. 2	D.B. 3
43	32	31	30	30	40	43	43	44
44	37	36	35	35	43	46	46	45
45	35	34	33	33	43	46	45	45
46	36	35	34	34	42	44	44	44
47	35	34	33	33	43	45	45	45
48	37	36	35	35	43	45	45	45
49	33	32	31	31	41	43	43	43
50	32	31	30	30	40	42	42	42
51	36	35	34	34	42	45	44	46
52	34	33	32	32	41	44	43	45
53	33	32	31	31	41	44	44	45
54	32	31	30	30	40	43	43	44
55	36	35	34	34	43	46	46	45
56	34	33	32	33	42	45	45	46
57	31	30	29	30	39	42	42	41
58	30	29	28	29	38	40	41	40
59	35	34	33	34	41	43	44	45
60	33	32	31	32	41	43	44	43

APPENDIX 4.2

Data collected during the composting process

Date	Pile	Pile Temperature (^oC)			CO_2 Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
16/5/99	S+BA (P)	52	46	63			
	S+BA+30%	63	53	58			
18/5/99	S+BA (P)	68	62,67,55	66	6	7.5,8.5,6	2.5
	S+BA+30%	64	72,70,68	68	6	5,5,0	2
	S+BA+40%	52	65	50	0	0,0,0	0
	S+BA (W)	46	45	46	20	6,11,20	20
20/5/99	S+BA (P)	65	67,71,63	63	3	6,7,5	4
	S+BA+30%	66	69,70,69	67	7	4,8,7	3
	S+BA+40%	65	71,71	65	1	2	1
	S+BA (W)	72	61	72	6	9,20	16
21/5/99	S+BA (P)	62	66,71,64	59	1	3,4,5	1
	S+BA+30%	60	48,67,68	62	2	0,0,4	2
	S+BA+40%	59	63	56	0	0	0
	S+BA (W)	67	65,65	63	4	7,12,16	2
22/5/99	S+BA (P)	66	68	60	2	2	3
	S+BA+30%	62	66,66	64	4	2,4,7	4
	S+BA+40%	59	68,65	55	0	0	0
	S+BA (W)	68	66,69	65	2	8,10,16	3
24/5/99	S+BA (P)	66	64,69,64	63	12	14,15,12	12
	S+BA+30%	65	67,69,67	68	8	12,10,5	8
	S+BA+40%	63	67,63	65	2	4,4,2	0
	S+BA (W)	70	66,67,65	67	5	10,19,20	13
25/5/99	S+BA (P)	65	66,69,57	66	5	9,10,6	7
	S+BA+30%	59	67,69,64	64	3	6,7,6	4
	S+BA+40%	63	60,59	58	4	4,2,0	0
	S+BA (W)	66	68	67	2	16,17,20	6
26/5/99	S+BA (P)	62	68,72	63	7	8,11,9	5
	S+BA+30%	62	68,68	67	4	3,3,1	4
	S+BA+40%	59	65,61	64	3	3,3,2	0
	S+BA (W)	66	66,68	68	4	11,14,17	5
27/5/99	S+BA (P)	64	66,69	61	8	10,12,11	11
	S+BA+30%	57	62,63	62	3	8,7,6	6
	S+BA+40%	58	64,62	55	2	3,1,0	0
	S+BA (W)	66	65,64	64	3	13,15,16	7
29/5/99	S+BA (P)	59	68,56	57	5	10,9,9	10
	S+BA+30%	66	65,68	66	5	7,8,8	3
	S+BA+40%	57	65,66	56	1	3,3,2	1
	S+BA (W)	70	65,64	66	4	10,12,13	6

Date	Pile	Pile Temperature (°C)			CO$_2$ Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
31/5/99	S+BA (P)	60	67,62	63	4	4,4,3	3
	S+BA+30%	57	64,57	60	4	3,3,5	5
	S+BA+40%	62	63,58	63	0	3,1,0	0
	S+BA (W)	62	64,61	66	0	8,10,10	1
6/6/99	S+BA (P)	59	60,65	60	6	4,6,7	6
	S+BA+30%	53	62,64	59	2	4,4,4	3
	S+BA+40%	58	62,59	61	1	1,1,1	2
	S+BA (W)	69	65,65	66	4	5,9,10	5
8/6/99	S+BA (P)	65	67,62	65	3	3,3	3
	S+BA+30%	56	64,59	60	2	2,2	4
	S+BA+10%	59	53,57	54	3	1,0	1
	S+BA+20%	53	54,53	54	1	1,0	0
	S+BA+40%	57	60	59	1	1,1	1
	S+BA (W)	67	64,61	67	2	6,11	4
	S+BA+25%	52	53,56	54			
	S+BA+50%	60	55,66	60	2	0	3
9/6/99	S+BA+25%	56	58,60	62	4	6,7,9	5
	S+BA+50%	65	62,66	61	1	0	0
	S+BA+10%	59	55,58	68	7	6,9,9	4
	S+BA+20%	48	44,49	52	1	0	4
10/6/99	S+BA+25%	67	63,63	69	4	6,11,11	6
	S+BA+50%	68	69,70	70	9	1,0	1
	S+BA+10%	72	70,73	74	7	12,13,13	5
	S+BA+20%	67	59,56	61	7	8,4,2	10
11/6/99	S+BA (P)	58	63,58	60	1	1,2	0
	S+BA+30%	52	59,58	58	1	2,2	1
	S+BA+40%	51	53	51	0	0	0
	S+BA (W)	67	66,60	66	1	5,7,8	1
	S+BA+25%	66	68,67	70	5	5,11,10	6
	S+BA+50%	68	69,71	71	1	0	0
	S+BA+10%	73	73,74	73	0	2,4,3	0
	S+BA+20%	68	66,65	64	8	9,12,10	7
	S+BA+35%	48	69	50	4	0	0
	S+30%	42	42	45			
12/6/99	S+BA+25%	66	66,65	67			
	S+BA+50%	60	69,72	67			
	S+BA+10%	70	72,73	67			
	S+BA+20%	66	66,65	66			
	S+BA+35%	61	64,67	59			
	S+30%	40	42,42	41			

Date	Pile	Pile Temperature (°C)			CO$_2$ Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
13/6/99	S+BA (P)	69	70,63	71	4	6,5	6
	S+BA+30%	67	70,65	71	1	1	3
	S+BA+40%	71	66	61	2	0	0
	S+BA (W)	70	55,53	68	2	14,20	8
	S+BA+25%	67	66,67	69			
	S+BA+50%	69	71,73	71			
	S+BA+10%	60	69,72	67			
	S+BA+20%	68	67,67	67			
	S+BA+35%	70	70,72	66			
	S+30%	41	44,42	42			
15/6/99	S+BA (P)	69	70,63	71	4	6,5	6
	S+BA+30%	67	70,65	71	1	1	3
	S+BA+10%	68	67	62	3	0	0
	S+BA+20%	65	58	58	0	0	0
	S+BA+40%	71	66	61	2	0	0
	S+BA (W)	70	55,53	68	2	14,20	8
16/6/99	S+BA (P)	71	68	72			
	S+BA+30%	66	66	66			
	S+BA+10%	64	70	61			
	S+BA+20%	55	62	53			
	S+BA+40%	67	73	69			
	S+BA (W)	63	60	58			
	S+30%	49	51	48			
19/6/99	S+BA (P)	68	69	69	4	8,12	4
	S+BA+30%	64	68	68	3	4	2
	S+BA+40%	71	65	68	1	1	0
	S+30%	64	62	64	0	0	0
	S+BA+25%	68	67	68	4	13,16	13
	S+BA+50%	72	72	71	11	7,6	8
	S+BA (W)	67	55	63	4	14	6
	S+BA+10%	64	69	67	7	6,7	11
	S+BA+20%	63	63	66	12	12,16	12
	S+BA+35%	68	68	63	11	9,10	10
21/6/99	S+BA (P)	62	69	66	4	5	6
	S+BA+30%	60	64	66	6	3	5
	S+BA+40%	69	65	66	1	1	1
	S+30%	66	65,60	64	0	0	0
	S+BA+25%	67	66	71	3	10,14	6
	S+BA+50%	71	73	73	12	8,5	11
	S+BA (W)	69	60	64	4	10	3
	S+BA+10%	71	70	75	9	7,8	6
	S+BA+20%	66	65	64	9	13,14	12
	S+BA+35%	67	63	67	10	11,10	9

Date	Pile	Pile Temperature (°C)			CO$_2$ Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
23/6/99	S+BA (P)	58	58	65	6	13	9
	S+BA+30%	65	66	65	10	9	12
	S+BA+40%	66	67	67	2	3	1
	S+30%	65	64	68	0	0	0
	S+BA+25%	62	60	62	11	14	16
	S+BA+50%	70	66	72	8	10	15
	S+BA (W)	55	56	58	10	12	10
	S+BA+10%	66	70	73	9	9	9
	S+BA+20%	63	61	63	9	12	11
	S+BA+35%	67	61	67	13	12	15
24/6/99	S+BA (P)	61	60	64	14	6	7
	S+BA+30%	52	55	62	6	8	11
	S+BA+40%	63	63	63	2	2	3
	S+30%	57	63	61			
	S+BA+25%	64	61	66	10	8	13
	S+BA+50%	66	67	65	8	7	10
	S+BA (W)	57	52	56	9	8	12
	S+BA+10%	69	71	69	5	3	9
	S+BA+20%	64	61	63	5	7	13
	S+BA+35%	67	66	65	5	11	13
26/6/99	S+BA (P)	57	53	54	7	5	8
	S+BA+30%	55	59	56	10	7	5
	S+BA+40%	60	60	60	1	2	2
	S+30%	65	65	62	0	2	0
	S+BA+25%	63	55	59	10	11	5
	S+BA+50%	63	63	66	12	12	11
	S+BA (W)	52	49	50	9	13	10
	S+BA+10%	64	66	60	7	7	10
	S+BA+20%	62	55	57	9	13	9
	S+BA+35%	70	62	60	6	8	9
28/6/99	S+BA (P)	57	56	58	11	6	3
	S+BA+30%	50	54	55	4	4	6
	S+BA+40%	57	51	54	0	0	0
	S+30%	61	62	57	3	3	2
	S+BA+25%	57	55	58	9	9	4
	S+BA+50%	66	67	69	12	9	8
	S+BA (W)	54	58	58	10	6	5
	S+BA+10%	60	63	68	13	9	4
	S+BA+20%	54	51	53	13	13	9
	S+BA+35%	62	62	61	14	9	7

Date	Pile	Pile Temperature (°C)			CO_2 Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
30/6/99	S+BA (P)	50	53	52	15	14	6
	S+BA+30%	44	51	51	10	11	11
	S+BA+40%	59	53	56	1	1	1
	S+30%	61	62	61	5	2	2
	S+BA+25%	54	51	49	17	15	6
	S+BA+50%	62	64	66	16	10	12
	S+BA (W)	52	50	53	11	13	13
	S+BA+10%	60	60	64	10	10	7
	S+BA+20%	55	52	54	16	17	10
	S+BA+35%	62	62	54	14	11	10
3/7/99	S+BA (P)	53	51	58	10	11	8
	S+BA+30%	50	51	50	9	6	6
	S+BA+40%	60	60	60	3	4	0
	S+30%	55	55	52			
	S+BA+25%	55	51	51	14	15	6
	S+BA+50%	62	63	65	10	8	12
	S+BA (W)	53	51	54	8	9	6
	S+BA+10%	63	61	61	5	6	10
	S+BA+20%	53	52	54	11	10	6
	S+BA+35%	59	58	52	11	10	7
5/7/99	S+BA (P)	48	49	47	7	6	3
	S+BA+30%	48	55	51	2	1	2
	S+BA+40%	54	51	56	0	0	0
	S+30%	59	58	56	3	5	2
	S+BA+25%	55	52	52	8	9	4
	S+BA+50%	63	65	67	7	4	4
	S+BA (W)	52	48	49	1	3	5
	S+BA+10%	63	59	58	5	4	1
	S+BA+20%	53	51	52	7	5	4
	S+BA+35%	61	55	53	6	4	3
9/7/99	S+BA (P)	50	50	52	5	5	3
	S+BA+30%	50	52	50	1	2	2
	S+BA+40%	55	54	51	0	0	0
	S+30%	59	60	60	0	0	0
	S+BA+25%	53	50	52	4	4	7
	S+BA+50%	63	65	64	5	7	4
	S+BA (W)	52	50	53	3	3	5
	S+BA+10%	59	56	60	5	4	2
	S+BA+20%	56	55	56	5	5	3
	S+BA+35%	59	54	55	3	5	4

Date	**Pile**	**Pile Temperature (°C)**			**CO_2 Evolution (%)**		
		Left end	**middle**	**Right end**	**Left end**	**middle**	**Right end**
17/7/99	S+BA (P)	51	52	48	1	0	3
	S+BA+30%	49	52	51	0	0	0
	S+BA+40%	56	56	50	0	0	0
	S+30%	65	65	59	1	1	1
	S+BA+25%	60	58	61	4	3	6
	S+BA+50%	59	63	63	2	4	2
	S+BA (W)	52	45	53	8	12	11
	S+BA+10%	61	60	55	3	6	5
	S+BA+20%	62	57	61	4	4	5
	S+BA+35%	59	57	55	4	4	2
21/7/99	S+BA (P)	49	46	45	0	0	0
	S+BA+30%	44	44	44	0	0	0
	S+BA+40%	34	44	36	0	0	0
	S+30%	62	63	61	0	0	0
	S+BA+25%	57	52	53	5	4	4
	S+BA+50%	60	63	58	4	4	5
	S+BA (W)	51	51	50	0	0	0
	S+BA+10%	61	61	55	2	3	1
	S+BA+20%	62	61	59	4	3	1
	S+BA+35%	57	55	52	3	4	4
27/7/99	S+BA (P)	58	59	55	-	3	-
	S+BA+30%	51	54	55	-	7	-
	S+BA+40%	60	56	59	-	4	-
	S+30%	61	63	59	3	4	3
	S+BA+25%	58	57	55	1	3	1
	S+BA+50%	62	59	58	3	4	2
	S+BA (W)	62	62	60	-	4	-
	S+BA+10%	57	55	54	1	3	1
	S+BA+20%	62	65	58	1	4	1
	S+BA+35%	55	52	54	6	6	4
31/7/99	S+BA (P)	-	61	-	-	0	-
	S+BA+30%	-	55	-	-	4	-
	S+BA+40%	-	58	-	-	4	-
	S+30%	61	61	46	2	3	2
	S+BA+25%	62	65	57	2	4	3
	S+BA+50%	62	65	61	0	0	0
	S+BA (W)	-	65	-	-	4	-
	S+BA+10%	58	58	57	3	4	2
	S+BA+20%	57	58	59	2	3	2
	S+BA+35%	55	54	55	6	4	4

Date	Pile	Pile Temperature (^oC)			CO_2 Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
4/8/99	S+BA (P)		55			1	
	S+BA+30%		52			3	
	S+BA+40%		55			2	
	S+30%	53	52	51	4	4	2
	S+BA+25%	51	52	53	3	5	3
	S+BA+50%	54	53	55	0	2	1
	S+BA (W)		52			0	
	S+BA+10%	52	51	50	3	3	2
	S+BA+20%	56	56	56	0	0	0
	S+BA+35%	47	46	46	2	3	3
15/8/99	S+BA (P)	-	50	-	-	5	-
	S+BA+30%	-	48	-	-	6	-
	S+BA+40%	-	50	-	-	9	-
	S+30%	53	51	47	-	8	-
	S+BA+25%	58	47	46	-	9	-
	S+BA+50%		52		-	10	-
	S+BA (W)	51	51	51	-	10	-
	S+BA+10%	64	54	49	-	7	-
	S+BA+20%	57	54	51	-	8	-
	S+BA+35%	51	52	49	-	10	-
18/8/99	S+BA (P)	-	50	-	-	4	-
	S+BA+30%	-	49	-	-	6	-
	S+BA+40%	-	52	-	-	9	-
	S+30%	-	66	-	-	9	-
	S+BA+25%	-	61	-	-	10	-
	S+BA+50%	-	56	-	-	10	-
	S+BA (W)	-	50	-	-	10	-
	S+BA+10%	-	64	-	-	9	-
	S+BA+20%	-	64	-	-	9	-
	S+BA+35%	-	56	-	-	10	-
23/8/99	S+BA (P)	-	50	-	-	4	-
	S+BA+30%	-	47	-	-	11	-
	S+BA+40%	-	47	-	-	9	-
	S+30%	-	61	-	-	7	-
	S+BA+25%	-	55	-	-	6	-
	S+BA+50%	-	54	-	-	5	-
	S+BA (W)	-	51	-	-	9	-
	S+BA+10%	-	55	-	-	7	-
	S+BA+20%	-	57	-	-	7	-
	S+BA+35%	-	54	-	-	8	-

Date	Pile	Pile Temperature (°C)			CO_2 Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
27/8/99	S+BA (P)	-	64	-	-	10	-
	S+BA+30%	-	44	-	-	10	-
	S+BA+40%	-	45	-	-	8	-
	S+30%	-	55	-	-	5	-
	S+BA+25%	-	54	-	-	11	-
	S+BA+50%	-	52	-	-	11	-
	S+BA (W)	-	51	-	-	10	-
	S+BA+10%	-	54	-	-	11	-
	S+BA+20%	-	65	-	-	10	-
	S+BA+35%	-	52	-	-	8	-
31/8/99	S+BA (P)	-	48	-	-	2	-
	S+BA+30%	-	38	-	-	7	-
	S+BA+40%	-	37	-	-	7	-
	S+30%	-	52	-	-	3	-
	S+BA+25%	-	50	-	-	8	-
	S+BA+50%	-	50	-	-	10	-
	S+BA (W)	-	46	-	-	8	-
	S+BA+10%	-	47	-	-	7	-
	S+BA+20%		40	-	-	7	-
	S+BA+35%	-	36	-	-	5	-
4/9/99	S+BA (P)	-	47	-	-	5	-
	S+BA+30%	-	41	-	-	10	-
	S+BA+40%	-	40	-	-	5	-
	S+30%	-	50	-	-	4	-
	S+BA+25%	-	49	-	-	3	-
	S+BA+50%	-	46	-	-	5	-
	S+BA (W)	-	44	-	-	5	-
	S+BA+10%	-	50	-	-	3	-
	S+BA+20%		49	-	-	1	-
	S+BA+35%	-	41	-	-	3	-
8/9/99	S+BA (P)	-	42	-	-	3	-
	S+BA+30%	-	37	-	-	11	-
	S+BA+40%	-	36	-	-	8	-
	S+30%	-	47	-	-	2	-
	S+BA+25%	-	48	-	-	9	-
	S+BA+50%	-	33	-	-	3	-
	S+BA (W)	-	42	-	-	2	-
	S+BA+10%	-	45	-	-	6	-
	S+BA+20%		47	-	-	3	-
	S+BA+35%	-	42	-	-	12	-

Date	Pile	Pile Temperature (°C)			CO_2 Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
12/9/99	S+BA (P)	-	36	-	-	8	-
	S+BA+30%	-	37	-	-	8	-
	S+BA+40%	-	51	-	-	4	-
	S+30%	-	63	-	-	7	-
	S+BA+25%	-	42	-	-	7	-
	S+BA+50%	-	41	-	-	9	-
	S+BA (W)	-	41	-	-	11	-
	S+BA+10%	-	42	-	-	6	-
	S+BA+20%		37	-	-	5	-
	S+BA+35%	-	44	-	-	13	-
22/9/99	S+BA (P)	-	41	-	-	10	-
	S+BA+30%	-	35	-	-	4	-
	S+BA+40%	-	34	-	-	4	-
	S+30%	-	41	-	-	2	-
	S+BA+25%	-	40	-	-	6	-
	S+BA+50%	-	40	-	-	6	-
	S+BA (W)	-	39	-	-	10	-
	S+BA+10%	-	40	-	-	4	-
	S+BA+20%		41	-	-	10	-
	S+BA+35%	-	35	-	-	9	-
26/9/99	S+BA (P)	-	41	-	-	5	-
	S+BA+30%	-	36	-	-	8	-
	S+BA+40%	-	34	-	-	2	-
	S+30%	-	38	-	-	2	-
	S+BA+25%	-	43	-	-	2	-
	S+BA+50%	-	42	-	-	6	-
	S+BA (W)	-	37	-	-	7	-
	S+BA+10%	-	35	-	-	2	-
	S+BA+20%		42	-	-	6	-
	S+BA+35%	-	36	-	-	3	-
30/9/99	S+BA (P)	-	38	-	-	11	-
	S+BA+30%	-	33	-	-	3	-
	S+BA+40%	-	34	-	-	5	-
	S+30%	-	37	-	-	3	-
	S+BA+25%	-	38	-	-	2	-
	S+BA+50%	-	37	-	-	6	-
	S+BA (W)	-	37	-	-	1	-
	S+BA+10%	-	36	-	-	4	-
	S+BA+20%		34	-	-	4	-
	S+BA+35%	-	32	-	-	6	-

Date	Pile	Pile Temperature (°C)			CO_2 Evolution (%)		
		Left end	middle	Right end	Left end	middle	Right end
4/10/99	S+BA (P)	-	37	-	-	6	-
	S+BA+30%	-	35	-	-	4	-
	S+BA+40%	-	32	-	-	2	-
	S+30%	-	35	-	-	1	-
	S+BA+25%	-	39	-	-	1	-
	S+BA+50%	-	38	-	-	3	-
	S+BA (W)	-	37	-	-	4	-
	S+BA+10%	-	33	-	-	1	-
	S+BA+20%		39	-	-	3	-
	S+BA+35%	-	37	-	-	7	-