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Fate of 1-(1′,4′-cyclohexadienyl)-2-methylaminopropane (CMP) in soil: Route-specific by-product in the clandestine manufacture of methamphetamine

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ABSTRACT

We investigated the fate of 1-(1′,4′-cyclohexadienyl)-2-methylaminopropane (CMP) in soil. CMP is the major route-specific byproduct in the clandestine manufacture of methamphetamine (MAP) by the use of excess alkali metal (e.g., lithium) in liquid ammonia, which is commonly referred to as the "Nazi method". This is one of the most common methods used in many countries for the illicit production of MAP. Knowledge on the fate of CMP in the terrestrial environment is essential to combat potential threats arising from illegal dumping of clandestine laboratory wastes. We report on the sorption–desorption, degradation, and metabolism patterns of CMP in three South Australian soils investigated in laboratory scale. CMP sorption in the test soils followed a Freundlich isotherm in the concentration range of 5 to 100 μg mL^{-1}. Degradation studies showed that CMP was fairly unstable in both non-sterile and sterile soils, with half-life values typically less than one week. The role of biotic and abiotic soil processes in the degradation of CMP also varied significantly between the different soils, and with the length of the incubation period. Interestingly, but not surprisingly, the results showed that the CMP was not actually degraded to any simpler compounds but transformed to more persistent MAP. Thus, the main concern with Nazi method is the potential hazard from MAP rather than CMP if wastes are disposed of into the environment.

1. Introduction

Illicit drug abuse is a serious global problem (Makino et al., 2005). The main group of illicit drugs falls into the categories of opiates, cocaine, cannabis, and amphetamines-type stimulants (ATSs) (Hall et al., 2008; UNODC, 2007). ATSs consist of two groups of substances: first the amphetamines group (e.g., amphetamine and methamphetamine); and second the ecstasy group (e.g., 3,4-methylenedioxymethamphetamine (MDMA) and analogous compounds) (UNODC, 2008a). Amphetamine group substances account for more than three-quarters of ATSs (UNODC, 2008b). Methamphetamine (MAP) continues to be the most widely manufactured ATS and accounted for 68% of the amphetamine groups in a 2006 estimate (UNODC, 2008a,b). In comparison with the plant-based drugs (e.g., heroin, cocaine, cannabis, etc.), MAP is relatively easy to manufacture in clandestine laboratories from commonly available chemicals (Sasaki and Makino, 2006). MAP manufacture is located throughout East and South-East Asia, North America and Oceania where there is high demand and ready availability of precursors (UNODC, 2008a). MAP is manufactured through variety of synthetic routes employing a range of precursors, most commonly in small clandestine laboratories, and also in industrialized mega and super laboratories (UNODC, 2008a). The clandestine manufacture of MAP involves a number of routes (e.g., Leuckart method, reductive amination, Birch reduction conditions, Nagai method, Rosenmund method, Emde method) as described by Sasaki and Makino (2006). Many of these give rise to route-specific byproducts (Qi et al., 2006, 2007).

The clandestine manufacture of MAP frequently involves pseudoephedrine and/or ephedrine as the precursor due to its ready availability. It is the most commonly used precursor used in the USA, Australia and New Zealand (UNODC, 2008a; Barker and Antia, 2007, Person et al., 2005). 1-(1′,4′-cyclohexadienyl)-2-methylaminopropane (CMP) is the route-specific byproduct of the clandestine manufacture of MAP by reduction of ephedrine or pseudoephedrine in presence of ammonia and excess lithium (Person et al., 2005; Zvilichovsky and Gbara-Haj-Yahia, 2004). The synthetic conditions are based upon those of the Birch reduction and the process is commonly referred to as the Nazi method by the forensic community (Person et al., 2005). CMP is formed by reduction of the aromatic ring of MAP in the presence of excess alkali metal after the initial cleavage of hydroxyl group of ephedrine (Barker and Antia, 2007; Person et al., 2005; Zvilichovsky and Gbara-Haj-Yahia, 2004). The basic information (e.g., IUPAC nomenclature, molecular formula, molecular weight, chemical structure) of CMP is given in Table 1.

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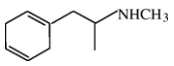
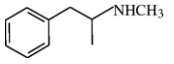
Table 1
General information on the target compounds in the present study.

Target compound		Molecular formula	Molecular weight	Molecular structure
IUPAC name	Short name			
1-(1′,4′-cyclohexadienyl)-2-methylaminopropane	CMP	$C_{10}H_{17}N$	151.25	
N-methyl-1-phenyl-propan-2-amine	MAP	$C_{10}H_{15}N$	149.24	

The wastes from clandestine drug laboratories are often illegally buried in soil or disposed of into sinks and toilets where they enter the sewerage system and public waste water treatment facilities (Janusz et al., 2003; Scott et al., 2003). However, there are no reports in the scientific literature on the environmental fate of this major by-product of illicit drug synthesis. In this paper we report investigations of the behavior of CMP in soils as the first steps in understanding the fate of this compound in the terrestrial environment. Thus, the present study will allow the environmental scientist to judge the potential hazard due to the release of these chemicals into the environment as well as the forensic scientists to accurately assess the environmental impact of clandestine drug laboratories and link the discarded residues with the method of manufacture.

2. Materials and methods

2.1. Soil

Samples of surface soils (0–15 cm) were collected from Mawson Lakes (ML) campus of University of South Australia, Sturt Gorge (SG), and Waite Campus (WC) of The University of Adelaide, South Australia, and correspond with soil that are urban impacted, native bush land, and agricultural land, respectively. The soils were stored in polyethylene buckets and brought to the laboratory. They were then screened to remove any plant parts or other debris, passed through 2 mm sieve, and then placed in refrigerated storage maintained at 4 °C.

The physico-chemical properties of the soils were measured following the standard analytical procedures and are shown in Table 2. The three soils varied widely in terms of organic carbon, clay content, soil texture, pH, and surface area. The pH (in 1:2.5 H_2O) of the soils ranged between 5.64 and 5.98 (slightly acidic) for WC and SG soils, respectively to 8.91 (alkaline) for ML soil. The cation exchange capacities of the soils ranged between 6.3 and 19.2 cmol (p+) kg^{-1} soil. The organic carbon content of the test soils varied in the descending order of 2.88 (SG) > 2.26 (WC) > 1.11% (ML), while the dissolved organic carbon (DOC) varied in the descending order of 8.71 (ML) > 5.84 (SG) > 3.90 μg mL^{-1} (WC). The soils contained a moderate level of clay (15–20%). The ML and SG soils were sandy loam while WC soil was loam in texture.

2.2. Experimental plan

Sorption experiments were conducted at 25 ± 1 °C and in the dark to avoid photodegradation. For this purpose, we used 50 mL capacity PTFE vials fitted with screw caps. The background solution was 0.01 M $CaCl_2$ in Milli-Q water. Stock solution (100 μg mL^{-1}) of CMP was prepared in 0.01 M $CaCl_2$ solution. Initially the sorption experiment was carried out at a single concentration of 100 μg mL^{-1} over a range of equilibration times (0, 1, 2, 4, 6, 12, 24, and 48 h). On the basis of these preliminary results, we chose five initial concentrations (5, 10, 20, 50, and 100 μg mL^{-1}) and 24 h equilibration time for the second phase of sorption experiment. To 5 g of air dried soil the requisite amount of the stock solution was added to produce the desired concentration. The background solution was maintained at 20 mL. Blank samples (without soil) were also maintained as a reference to check the initial concentration. In addition, control soils receiving blank 0.01 M $CaCl_2$ solution were also maintained. All the experiments were conducted in duplicate. The vials were shaken in an end-over-end shaker at 10 rpm. The supernatants were then centrifuged at 3000 rpm for 15 min and passed through 0.45 μm filter for direct analysis in HPLC-MS. The amount adsorbed was determined as the difference between the initial and final concentrations of the CMP in solution.

Desorption studies were conducted only for the 20 μg mL^{-1} concentration. For this purpose, the aliquot from the sorption study was discarded and replaced by the background solution (20 mL). The vials were shaken under the same experimental conditions for 24 h and using similar procedures to the sorption experiment. The amount desorbed was estimated on the basis of the mass balance calculation.

The degradation patterns of CMP were studied both under the non-sterile and sterile conditions. The moisture level was adjusted at 50% of MWHC (maximum water holding capacity) and the soils were incubated at 25 °C in a constant temperature room. To avoid any chance of photodegradation the soils were incubated in the dark. Five grams of soil in individual amber colored glass vials fitted with Teflon-lined solid screw caps was pre-incubated at 25 °C in the dark for one week. To begin sterile degradation the individual vials of soil were autoclaved for 20 min at 121 °C on three consecutive days. Sterile conditions were maintained throughout the study period and affirmed periodically by a microbiological plating technique.

The soils were spiked with 100 μg g^{-1} of CMP. For this purpose, the stock solutions (2 g L^{-1}) were prepared in water. The soils for both the non-sterile and sterile degradation experiments were spiked with the requisite amount of the freshly prepared stock solution. For sterile degradation the stock solutions were passed through sterile 0.45 μm filters, and the soils were spiked aseptically within a laminar air flow. The soils were vortexed for homogenization. Control soils were also maintained for both the non-sterile and sterile conditions. The moisture content of the soils (both in non-sterile and sterile) was maintained by aseptic addition of sterile Milli-Q water. All the experiments were conducted in duplicate for three month period.

2.3. Extraction procedure

In this study, CMP and MAP were extracted from soil with 40 mL of chloroform: acetonitrile: methanol: acetic acid (80:10:9:1) in two steps (20 mL each). The soils were vortexed and extracted two times on an electric shaker for the period of 1 h and 15 min, respectively, each

Table 2
Basic physico-chemical properties of the experimental soils.

Soil	Short name	pH (1:2.5 H_2O)	Electrical conductivity (μS cm^{-1})	Cation exchange capacity (meq-100 g^{-1})	Organic carbon (%)	Dissolved	Particle size distribution			Textural class
						Organic carbon (μg mL^{-1})	Sand (%)	Silt (%)	Clay (%)	
Mawson Lakes	ML	8.91	159	19.24	1.11	8.71	55.0	25.0	20.0	Sandy loam
Sturt Gorge	SG	5.98	36	6.30	2.88	5.84	60.0	25.0	15.0	Sandy loam
Waite Campus	WC	5.64	965	17.42	2.26	3.90	42.5	42.5	15.0	Loam

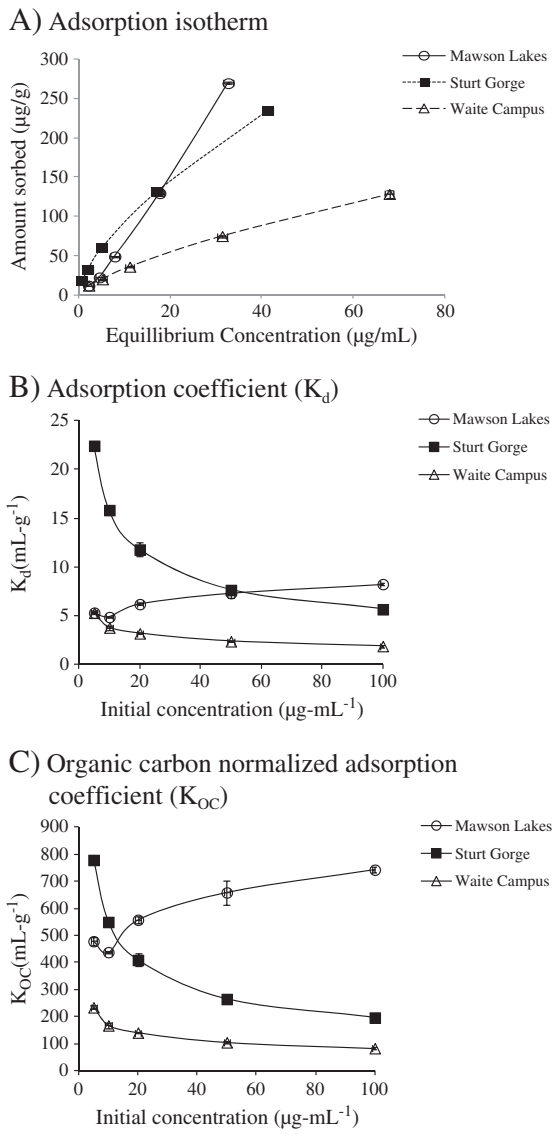


Fig. 1. Adsorption parameters of 1-(1,4-cyclohexadienyl)-2-methylaminopropane (CMP) as a function of concentration.

followed by ultrasonic vibration for 5 min at 30 °C. In each of the extraction steps the vials were centrifuged and the aliquots were filtered through 0.22 µm Teflon filters. The aliquots were combined, evaporated under a nitrogen stream and re-dissolved with HPLC grade methanol for direct HPLC analysis.

2.4. Determination of CMP and MAP

The determination of CMP and MAP was performed using HPLC (Agilent 1100 series) equipped with an auto-sampler, binary pump system and mass selective detector (Agilent 1100) with positive ionization mode of Atomic Pressure Ionization–Electro Spray (API–ES). Data integration was done by Chemstation software. Chromatographic separation

Table 3
Sorption parameters for the 1-(1,4-cyclohexadienyl)-2-methylaminopropane (CMP) in three experimental soils.

Soil	Freundlich parameters		
	K_F	n	r^2
Mawson Lakes	4.20	0.84	0.99
Sturt Gorge	20.33	1.52	0.99
Waite Campus	6.39	1.41	0.99

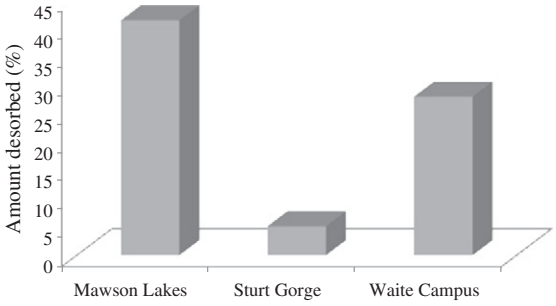


Fig. 2. Desorption pattern of 1-(1,4-cyclohexadienyl)-2-methylaminopropane (CMP).

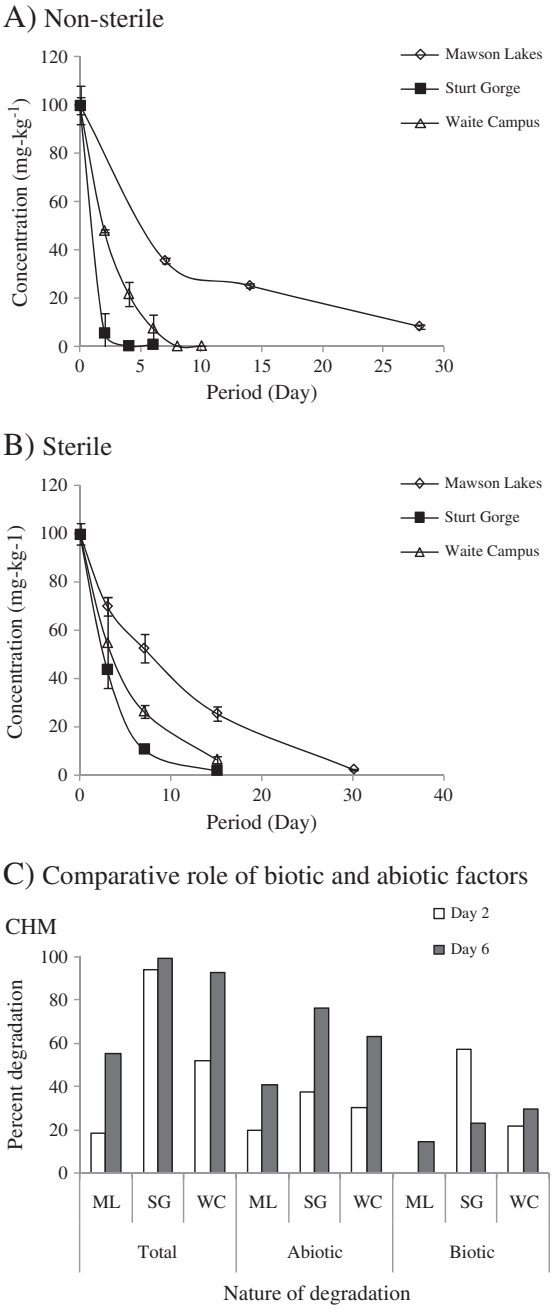


Fig. 3. Degradation patterns of 1-(1,4-cyclohexadienyl)-2-methylaminopropane (CMP) in three experimental soils.

Table 4
Regression equation, degradation rate constant (k), half-life ($t_{1/2}$), and correlation coefficient (r^2) values for the degradation of 1-(1,4-cyclohexadienyl)-2-methylaminopropane (CMP) in the experimental soils.

Soil	Sterility	Regression equation	k (Day^{-1})	$t_{1/2}$ (Day)	r^2
Mawson Lakes	*Non-sterile*	$y=-0.0364x+2.9165$	0.0364	8.3	0.9666
Sturt Gorge		$y=-0.3834x+2.6694$	0.3834	0.8	0.7668
Waite Campus		$y=-0.2930x+3.2280$	0.2930	1.0	0.8834
Mawson Lakes	*Sterile*	$y=-0.0534x+2.0577$	0.0534	5.64	0.9783
Sturt Gorge		$y=-0.1157x+1.9607$	0.1157	2.60	0.9890
Waite Campus		$y=-0.0777x+1.9839$	0.0777	3.87	0.9991

of the CMP and MAP were made using a ZORBAX Eclipse XDB-C18 150×4.6 mm, 5 μm column operated at 25 °C. The mobile phase consisted of two combinations of solvent A (20% methanol + 0.1% acetic acid + 10 mM ammonium acetate) and solvent B (90% methanol + 0.1% acetic acid + 10 mM ammonium acetate) maintaining a flow-rate of 0.8 mL min^{-1}. The timetable for the operation of mobile phase for the total run time (26 min) was 0–8 min (100% A), 8–12 min (90% A + 10% B), 12–25 min (100% B), and 25–26 min (100% A). The mass spectra were collected over the mass range of 100–350 m/z. The ions monitored for CMP were 152.2 m/z and 121.2 m/z, while for MAP 150.2 m/z and 119.2 m/z. Propranolol was used as the internal standard during the analysis.

The detection limit and limit of quantification values are the concentrations producing signal-to-noise ratio of 3:1 and 10:1. The detection limits of the analytical system were 0.05 (MAP) and 0.11 ng (CMP) while the limits of quantification were 127 (MAP) and 297 ng g^{-1} (CMP). The analytical method for CMP and MAP showed a good linearity ($R^2>0.99$) and repeatability ranged between 2 and 5% RSD. The average recovery of the analytical procedures was 70% for both MAP and CMP.

3. Results and discussion

3.1. Sorption–desorption pattern

The sorption pattern of CMP in the test soils was determined as a function of its initial concentration. The sorption isotherms were checked at initial concentrations of 5 through to 100 μg mL^{-1}. The data were fitted both to the Langmuir and Freundlich isotherm. The Langmuir isotherm assumes monolayer sorption, while the Freundlich isotherm is an empirical relationship describing the sorption of solute to solid surface (Voudrias et al., 2002). The results showed a concentration dependent sorption isotherm with steady increases up to the maximum concentration level (Fig. 1A). The sorption curves were well described by Freundlich isotherms. The Freundlich isotherms can be expressed as $\log C_s = \log K_F + (1/n)\log C_e$ (plot of $\log C_s$ vs. $\log C_e$ gives a straight line with the slope = 1/n and intercept = $\log K_F$) where, C_e is the equilibrium concentration of CMP (μg mL^{-1}), C_s is the amount of CMP adsorbed per unit soil (μg g^{-1}), C_m is the maximum amount adsorbed as C_e increases, and K values (μg g^{-1}) represent the amount of CMP adsorbed per unit soil for $C_e = 1$. In the Freundlich equation, when 1/n = 1 we can calculate the adsorption coefficient as K_d (mL g^{-1}) = C_s/C_e, which upon normalization in terms of

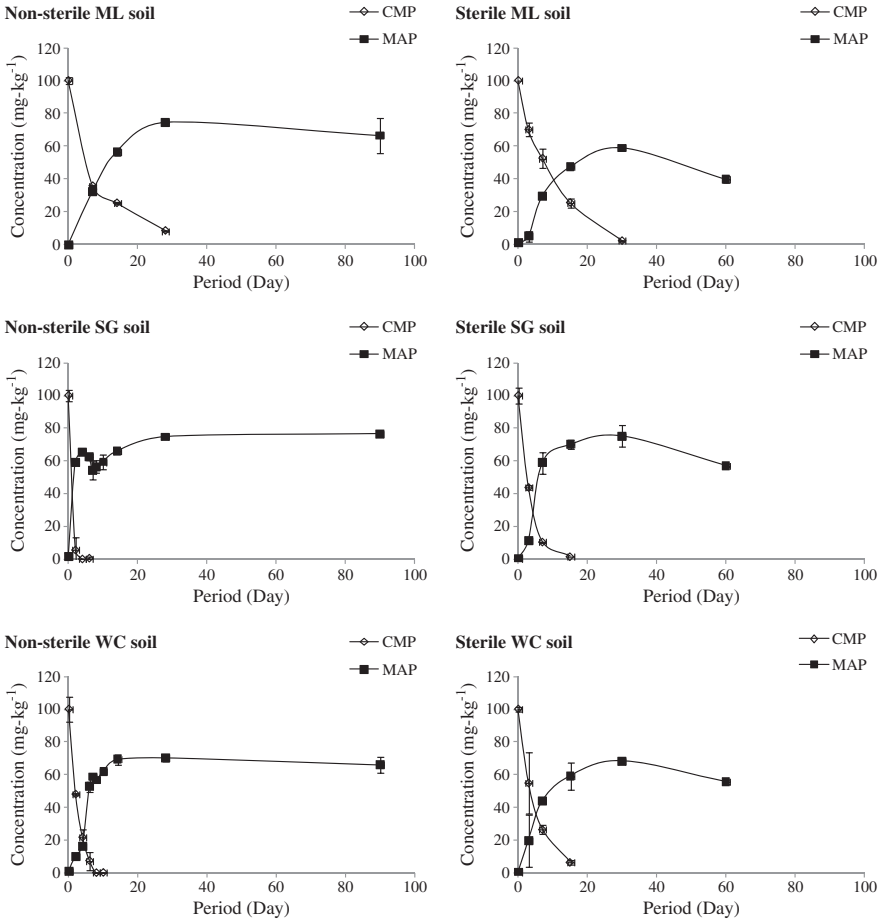


Fig. 4. A plot for the formation of MAP due to the transformation of CMP at different period of incubation both in non-sterile and sterile soils.

organic carbon (OC) gives $K_{OC} = K_d(100/OC)$. A summary of the sorption parameters is presented in Table 3.

The SG soil recorded the highest K value indicating maximum sorption potential and the values decreased in the order of SG > WC > ML. As well as exhibiting the lowest K value the ML soil also had the lowest OC content. The low K value might be ascribed to the nature of the organic matter producing high DOC that competes with CMP for sorption sites. However, there were too few soils to make any general conclusions regarding soil properties and CMP sorption. For better understanding of the sorption pattern, the results were analyzed with different exploratory approaches. The adsorption coefficient (K_d) and organic carbon normalized adsorption coefficient (K_{OC}) were calculated for all the treatment cases. In Fig. 1B and C, the results of K_d and K_{OC} were compared between the soils as a function of the initial concentrations. In general, the K_d values when compared between test soils were seen to decrease in the following order: SG > ML > WC (Fig. 1B). The test soils also showed a widely different pattern across the concentration range. The SG and WC soils recorded a steady decrease in K_d values with increase in the initial concentration of CMP while a reverse trend was apparent for ML soil. The partitioning of organic compounds in soils is generally proportional to the OC content of the particular soil (Novoszad et al., 2005). Thus, K_d values are commonly normalized to OC (K_{OC}). However, the K_{OC} values show the same wide variation as the K_d values among the test soils, which might be due to the relatively large differences between the OC content of each soil (Fig. 1C).

The desorption potential of CMP was found to be in the following descending order: ML (41.4%) > WC (27.9%) > SG (5.1%) (Fig. 2). The lowest desorption potential of CMP from SG soil is in line with the highest K_d and K_{OC} values for this soil. The major part of CMP in SG soil was irreversibly sorbed, presumably by soil organic matter (OM) and clay.

3.2. Degradation pattern

The degradation of CMP both in non-sterile and sterile soils is presented in Fig. 3. The results showed relatively similar persistence behavior irrespective of the experimental conditions and soils. In general, a sharp initial decrease in the CMP concentration was shown for both the non-sterile and sterile SG and WC soils, while a relatively slower rate was recorded for the ML soil (Fig. 3A and B). CMP persisted for 1–4 weeks irrespective of soils. The regression equation, regression coefficient (r^2), rate constant (k^{-1}), and half-life ($t_{1/2}$) values for the degradation of CMP both in non-sterile and sterile conditions is presented in Table 4. The experimental data were fitted to linear regression equation. The half-life values were calculated from the best fit lines of the logarithm of residual concentrations vs. time elapsed in the incubation period. The half-life values for the non-sterile soils ranged from 0.8 (SG) to 8.3 (ML) days, while the same for the sterile soils were 2.60 (SG) to 5.64 (ML) days. The results showed that the degradation potential of CMP both under non-sterile and sterile conditions followed the similar descending order: ML > WC > SG. In addition, almost a parallel degradation pattern of CMP both under non-sterile and sterile conditions indicated the dominant role of the soil abiotic factors compared to biotic components.

The degradation of CMP was conducted in amber color glass vials in the dark to eliminate any chance of photodegradation. Therefore CMP degradation observed in sterile soils was only due to the physico-chemical properties of soils. A comparison of the degradation of CMP due to abiotic and biotic soil processes at days 2 and 4 are shown in Fig. 3C. The biotic and abiotic factors showed an increasing pattern over time for all the soils with the single exception being biotic degradation in SG soil. For both incubation periods, abiotic soil

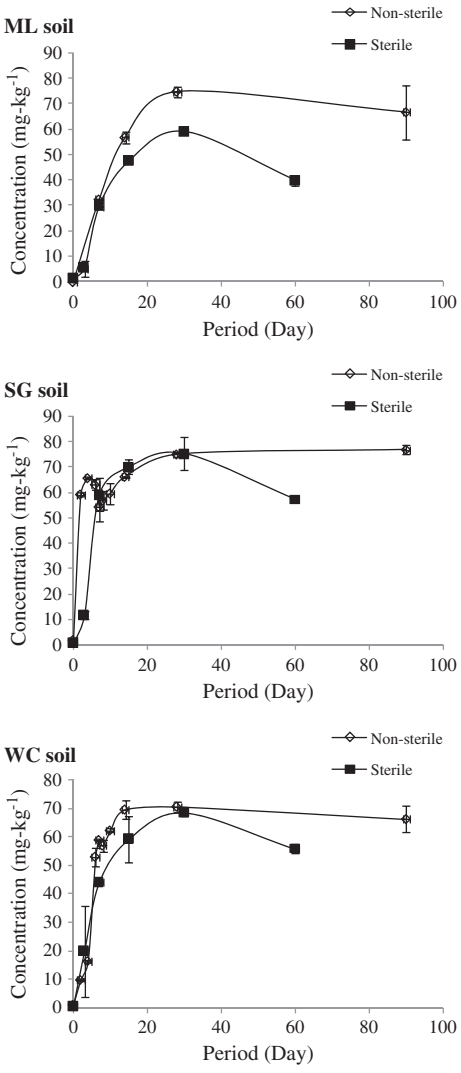


Fig. 5. A plot to compare the potential of biotic-abiotic factors in the formation of MAP due to CMP transformation in three soils at different period of incubation.

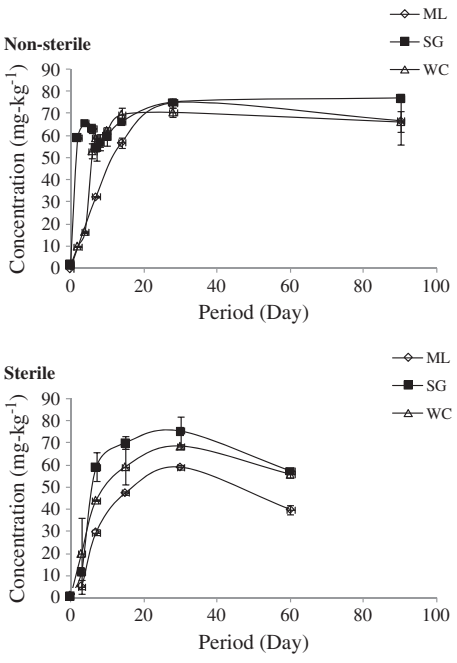


Fig. 6. A plot to compare the potential of MAP formation due to CMP transformation among the soils at different period of incubation under non-sterile and sterile conditions.

factors were found to be the greatest in SG soil followed by WC and ML soils. On the other hand, biotic degradation followed the order of ML<SG<WC for day 6, while a reverse pattern was apparent for day 2. The interplay between biotic and abiotic processes of individual soils thus has a major influence on the overall CMP degradation pattern.

3.3. Metabolism of CMP

When we investigated the chromatograms for the degradation of CMP both under non-sterile and sterile conditions, a peak at the same retention time as MAP was detected in each case after day zero. In full scan positive ionization mode of ES–MS analysis, the most abundant ion detected from that peak was 150.2 m/z, the $(M+H)^+$ ion, followed by 119.2 $[(M+H-CH_3NH)^+]$ (Supplementary figures S1–S3), this and the fragmentation pattern of the target peak confirmed the identification of MAP (Jones-Lepp et al., 2004; Castiglioni et al., 2006). To confirm further, we analyzed the soil extracts spiked with a known amount of MAP standard. The spiked MAP, 150.2 m/z ion, co-eluted at the same retention time with the original 150.2 m/z ion in the unspiked sample extract. The stability of CMP in methanol and the extraction solvent was also determined to examine whether the conversion of CMP to MAP was occurring in the soil or during the soil extraction processes but MAP was not detected.

In Fig. 4, data are plotted to show the formation of MAP from 1-(1,4-cyclohexadienyl)-2-methylaminopropane at different periods of incubation, both in non-sterile and sterile soils. The results revealed that the maximum formation of MAP occurred within the first four weeks of incubation in all the soils irrespective of experimental conditions. The data are re-displayed in Figs. 5 and 6 in order to highlight the differences in MAP production caused by different types of soil and sterile and non-sterile conditions.

4. Conclusions

The results of the present study suggest that the metabolism of CMP is mainly by transformation to MAP and not degradation in simpler compounds. The behavior and environmental fate of MAP in agricultural soils under sterile and non-sterile conditions over a 6 week period have been reported earlier by our research group (Janusz et al., 2003). Although degradation was recorded in the initial 12 days of incubation, the concentrations remained nearly constant after this period, and two-third of the initial concentration was still recorded after six weeks. We have recently reported upon the degradation pattern of MAP in the three test soils used in the current study under non-sterile conditions for more than one year (Pal et al., 2011); half-life values for MAP were ranged from 131 days (SG soil) to 502 days (WC soil) under non-sterile condition. The results show that the major environmental concern for manufacture of MAP via the Nazi method is the fast transformation of its main by-product CMP to MAP, which is extremely persistent and may be a hazard.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.scitotenv.2011.11.023.

References

Barker WD, Antia U. A study of the use of Ephedra in the manufacture of MAP. Forensic Sci Int 2007;166:102–9.
Castiglioni S, Zuccato E, Crisci E, Chiabrando C, Fanelli R, Bagnati R. Identification and measurement of illicit drugs and their metabolites in urban wastewater by liquid chromatography–tandem mass spectrometry. Anal Chem 2006;78:8421–9.
Hall W, Degenhardt L, Sindicich N. Illicit drug use and the burden of disease. In: Heggenhougen K, Quah S, editors. International Encyclopedia of Public Health. Elsevier; 2008. p. 523–30.
Janusz A, Kirkbride KP, Scott TL, Naidu R, Perkins MV, Megharaj M. Microbial degradation of illicit drugs, their precursors, and manufacturing by-products: implications for clandestine drug laboratory investigation and environmental assessment. Forensic Sci Int 2003;134:62–71.
Jones-Lepp TL, Alvarez DA, Petty JD, Huckins JN. Polar organic chemical integrative sampling and liquid chromatography–elctrospray/ion trap mass spectrometry for assessing selected prescription and illicit drugs in treated sewage effluents. Arch Environ Contam Toxicol 2004;47:427–39.
Makino Y, Urano Y, Nagano T. Investigation of the origin of ephedrine and MAP by stable isotope ratio mass spectrometry: a Japanese experience. Bull Narc 2005;LVII:63–78.
Novoszad M, Gerzabek MH, Haberhauer G, Jakusch M, Lischka H, Tunega D, Kirchmann H. Sorption of naphthalene derivatives to soils from a long-term field experiment. Chemosphere 2005;59:639–47.
Pal R, Megharaj M, Kirkbride KP, Heinrich T, Naidu R. Biotic and abiotic degradation of illicit drugs, their precursor and by-products in soil. Chemosphere 2011;85:1002–9.
Person EC, Meyer JA, Vyvyan JR. Structural determination of the principal byproduct of the lithium-ammonia reduction method of MAP manufacture. J Forensic Sci 2005;50:1–9.
Qi Y, Evans ID, McCluskey A. Australian federal police seizure of illicit crystalline MAP ('ice') 1998–2002: impurity analysis. Forensic Sci Int 2006;164:201–10.
Qi Y, Evans ID, McCluskey A. New impurity profiles of recent Australian imported 'ice': MAP impurity profiling and the identification of (pseudo)ephedrine and Leuckart specific marker compounds. Forensic Sci Int 2007;169:173–80.
Sasaki T, Makino Y. Effective injection in pulsed splitless mode for impurity profiling of MAP crystal by GC or GC/MS. Forensic Sci Int 2006;160:1-10.
Scott TL, Janusz A, Perkins MV, Megharaj M, Naidu R, Kirkbride KP. Effect of amphetamine precursors and by-products on soil enzymes of two urban soils. Bull Environ Contam Toxicol 2003;70:824–31.
UNODC (United Nations Office on Drugs and Crime). World Drug Report. United Nations publication; 2007 http://www.unodc.org/pdf/research/wdr07/WDR_2007.pdf [Accessed on May 16, 2011].
UNODC (United Nations Office on Drugs and Crime). World Drug Report. United Nations publication; 2008a http://www.unodc.org/documents/wdr/WDR_2008/WDR_2008_eng_web.pdf [Accessed on May 16, 2011].
UNODC (United Nations Office on Drugs and Crime). Amphetamines and ecstasy: global ATS assessment. United Nations publication; 2008b http://www.unodc.org/documents/scientific/ATS/Global-ATS-Assessment-2008-Web.pdf [Accessed on May 16, 2011].
Voudrias E, Fytianos K, Bozani E. Sorption–desorption isotherms of dyes from aqueous solutions and wastewaters with different sorbent materials. Global Nest J 2002;4:75–83.
Zvilichovsky G, Gbara-Haj-Yahia I. Birch reduction of (−)-ephedrine. Formation of a new, versatile intermediate for organic synthesis. J Org Chem 2004;69:5490–3.