National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Update of ecological risk limits for arsenic in soil

RIVM Letter report 2015-0138

R. van Herwijnen | J. Postma | R. Keijzers

Update of ecological risk limits for arsenic in soil

RIVM Letter report 2015-0138

R. van Herwijnen│J. Postma│R. Keijzers

Colophon

R. van Herwijnen, RIVM
J. Postma, Ecofide
R. Keijzers, Ecofide

Contact:
René van Herwijnen
Centre for Safety of Substances and Products
rene.van.herwijnen@rivm.nl

This investigation has been performed by order and for the account of Ministry of Infrastructure and the Environment, within the framework of the project M607711 Soil quality and Risk assessment.

This is a publication of:
National Institute for Public Health and the Environment
P.O. Box 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl/en

Publiekssamenvatting

Herziening van ecologische risicogrenzen voor arseen in bodem
Het RIVM heeft nieuwe Nederlandse ecologische risicogrenzen bepaald voor arseen in de bodem. Deze grenzen geven aan bij welke concentraties arseen schadelijke effecten op het ecosysteem in de bodem kan veroorzaken. De nieuwe risicogrenzen zijn strenger, om bacteriën en schimmels te beschermen tegen hoge arseenconcentraties. Bacteriën en schimmels zijn belangrijk om de bodem gezond te houden maar blijken heel gevoelig te zijn voor arseen. Als ze door de aanwezigheid van een kleine hoeveelheid van deze stof minder goed functioneren, kan er in de bodem bijvoorbeeld een tekort ontstaan aan bepaalde voedingsstoffen.

Arseen is een stof die van nature in de Nederlandse bodem zit. Ook door menselijke activiteit kan arseen de bodem hebben vervuild. Arseen is lange tijd veel gebruikt, bijvoorbeeld in verf en lijm of als bestrijdingsmiddel. Aangezien arseen een kankerverwekkende stof is, is het gebruik ervan sinds 2004 steeds meer aan banden gelegd.

Interventiewaarden en Maximale Waarden bodem
De nieuwe risicogrenzen zijn bepaald omdat de huidige van 2001 dateren en op beperkte gegevens zijn gebaseerd. Risicogrenzen zijn nodig om de zogeheten interventiewaarden en Maximale Waarden bodem te kunnen bepalen. Als de interventiewaarde wordt overschreden, komt de bodem in aanmerking voor sanering. Maximale Waarden zijn van belang om te bepalen of de grond in verband met hergebruik op een andere locatie mag worden verplaatst (grondverzet).

De risicogrenzen voor bodem
Voor deze doeleinden zijn in totaal twee risicogrenzen bepaald: de Ernstige Toevoeging (ET) en de Maximaal Toelaatbare Toevoeging (MTT). De Ernstige Toevoeging is de concentratie waarbij schadelijke effecten van de stof voor het bodemecosysteem te verwachten zijn. De bepaalde ET voor de bodem is 0,26 milligram per kilogram drooggewicht bodem. De Maximaal Toelaatbare Toevoeging (MTT) voor arseen in de bodem is bepaald op 0,0012 milligram per kilogram drooggewicht bodem. Onder dit niveau zijn geen negatieve effecten voor het ecosysteem in de bodem te verwachten.

In beide risicogrenzen is nog niet verrekend hoeveel arseen er van nature in de bodem zit (de achtergrondconcentratie). De achtergrondconcentratie moet dus nog bij de risicogrenzen worden opgeteld. Het RIVM heeft daar na een separaat onderzoek ook een voorstel voor gedaan.

Kernwoorden: arseen, Maximaal Toelaatbaar Risiconiveau, Ernstig Risico niveau, interventiewaarde, ecologische risicogrenzen

Synopsis

Update of ecological risk limits for arsenic in soil
The RIVM has derived new Dutch risk limits for arsenic in soil. These risk limits are soil concentrations above which negative effects can be expected for the soil ecosystem. The new risk limits are lower to protect bacteria and fungi against high levels of arsenic. Bacteria and fungi are important to keep the soil healthy but appear to be very sensitive for arsenic. The presence of a small amount of this substance could inhibit their processes which in turn could result in a deficiency of certain soil nutrients.

Arsenic is a substance that is naturally present in the Dutch soil. Human activity could have caused soil contamination. Historically, arsenic has been used in glue and paint or as a biocide. Because it is a carcinogen, the use of arsenic has been restricted since 2004.

Soil intervention values
The new risk limits have been derived because the current date back to 2001 and are based on a limited dataset. The new risk limits are needed to derive soil intervention values and maximum values. When soil concentrations exceed these values, remediation of the soil should be investigated. Maximum values are used to determine if soils can be reused at other location.

Ecological risk limits for soil and groundwater
For this purpose, two kinds of ecological risk limits have been derived: the Serious Risk Addition (SRA) and the Maximum Permissible Addition (MPA). The SRA is the concentration at which harmful effects are expected for the soil ecosystem. The derived SRA for arsenic in soil is 0.26 milligram per kilogram dry weight soil. The MPA has been derived to be 0.0012 milligram per kilogram dry weight soil. Below this level, negative effects for the soil ecosystem are unlikely.

Both risk limits do not include the natural background concentration for arsenic. The natural background concentration of arsenic in Dutch soils should be added to these values. After separate research, the RIVM has also proposed a new value for this.

Keywords: arsenic, Maximum Permissible Concentration, Serious Risk Concentration, soil intervention values, ecological risk limits

Contents

Summary

In this report new ecological risk limits (ERLs) are derived for arsenic in soil. The risk limits are derived using ecotoxicological data originating from an evaluation of the available recent literature. It should be noted that the proposed risk limits are scientifically derived values. They will be used as input for new intervention values for arsenic in soil. The current risk limits were derived in 2001, when only three terrestrial ecotoxicity endpoints covering two taxonomic groups were available.

Two types of ERLs are derived, both expressed as concentrations that may be added to the background concentration: a Maximum Permissible Addition (MPA) to protect against the occurrence of prolonged exposure and a Serious Risk Addition (SRA), a level where potentially 50% of the species is at risk and/or bacterial or enzymatic processes are severely inhibited. For the ERLs in this report only assessment of direct toxicity is considered. Secondary poisoning of birds and mammals has not been examined since exposure through consumption of worms is considered unlikely. Secondary poisoning of animals consuming arsenic accumulating plants is not excluded but could not be assessed because relevant guidance is not available.

An overview of the derived environmental risk limits is given in Table 1. The proposed $MPA_{soil,\ eco}$ and $SRA_{soil,\ eco}$ are lower than the current risk limits. The main reason for this are studies on the effects of arsenic on soil processes, effects which were not considered for the current risk limits. New studies for individual species also indicate that the current risk limits are not sufficiently protective.

Table 1. Summary of proposed ERLs for arsenic in soil.

	Value [mg As/kg$_{dwt}$]
$MPA_{soil,\ eco}$	0.0012
$SRA_{soil,\ eco}$	0.26
Intermediate ecological addition	0.024
Background concentration (Cb) currently used in Dutch soil policy with soil type correction	20
Revised background concentration (Cb) with alternative soil type correction	17

1 Introduction

1.1 Arsenic

Arsenic is a substance that is naturally present in the Dutch soil. However, human activity could have caused soil contamination. Historically, arsenic has been used in glue and paint or as a biocide. Because it is a carcinogen, the use of arsenic has been restricted since 2004. In the European Union, there are currently no registrations of arsenic under REACH and use is limited, in some cases it is still allowed for example for the treatment of wood that is professionally used.

1.2 Background of the report

Ecological risk limits play an important role in the Dutch soil protection policy. Together with human health related risk limits, they are used for assessment of soil quality in the context of decision making on remediation, re-use of soil and risk management in case of chemical spills or other emergency situations.
The derivation of most risk limits was performed in 2001 [1], mostly based on data from ecotoxicity tests that had been evaluated previously [2-6], but using an adapted methodology. Since then, risk limits for some (groups of) compounds have been updated (by adding new data to the already available datasets and taking into account methodological developments [7,8], but the majority of the currently used ecological risk limits originates from the 2001-report. Upon request of the Dutch Ministry of Infrastructure and the Environment, it was investigated to what extent the existing ecological risk limits for soil can (should) be improved to meet new scientific developments and to solve practical problems that arise when using those risk limits in practice [9]. As a follow-up, a scoring method was developed to rank the existing ecological risk limits with respect to uncertainty related to data quality and changes in methodology [10]. Based on this evaluation, arsenic amongst others was selected for a closer review.
Before focusing on this specific compound, the following sections give some background information on the risk limits considered in this report.

1.3 Relevant risk limits

The relevant ecological risk limits in the context of this report are the Maximum Permissible Concentration (MPC) and the Serious Risk Concentration (SRC) for the element arsenic in aerobic soils.
The MPC_{soil} is defined as the concentration in soil at which no negative effect on ecosystems is expected [11,12].
The MPC_{soil} in this report is derived considering direct ecotoxicity to soil organisms and/or bacterial or enzymatic processes ($MPC_{soil, eco}$).
Secondary poisoning of birds and mammals ($MPC_{soil, secpois}$) has not been examined since secondary poisoning by consumption of worms is considered unlikely. Consumption of arsenic accumulating plants is however also a potential route of exposure. This route has not been assessed because relevant guidance is not available. Considering the protection level and methodology, the $MPC_{soil, eco}$ is comparable to a Predicted No Effect Concentration (PNEC) as derived in various

international frameworks [13,14]. The derivation of the $MPC_{soil, eco}$ is based on the risk assessment as outlined in European guidance [13-15]. The SRC_{soil} is usually derived for direct ecotoxicity to soil organisms and/or processes only. The $SRC_{soil, eco}$ is the environmental concentration at which possibly serious ecotoxicological effects on soil organisms and/or processes are to be expected, meaning that 50% of the species or processes is potentially affected. Detailed guidance for the derivation of the MPC and SRC for soil is given in Van Vlaardingen and Verbruggen [16]. In addition to the MPC_{soil} and SRC_{soil}, an intermediate risk level is presented that represents a limit concentration for the re-use of soil for residential functions in The Netherlands. In line with the methodology described in [17], this intermediate ecological addition is set equal to the geometric mean of the ecologically based MPC_{soil} and SRC_{soil}.

1.4 Current risk limits

In 2001 [1] an SRA of 56 mg/kg and an MPA of 0.9 mg/kg were derived. For this derivation, two NOECs for plants and one for a worm were available. The SRA was calculated as the geometric mean of these three values and the MPA was derived from the lowest NOEC with an assessment factor of 50.

Currently, the (natural) background value of 20 mg/kg_{dwt} as derived according to the AW2000 method (Background values 2000)[18,19] is used in the Dutch soil policy. There is however a second reference value available of 29 mg/kg_{dwt} derived according to the INS method (INS) [1,3] and also a new value of 17 mg/kg_{dwt} has recently been derived based on an alternative approach[1] to the default soil type correction [20]. The AW2000 background values are based on the 95% percentile of the soil concentrations in the upper 10 cm layer of soils in areas that are unsuspected with respect to anthropogenic pollution [18,19]. The INS values are based on the 90% percentile values of regression lines describing the relationship between organic matter and clay and concentrations found in relative unpolluted sites in the Netherlands, the so-called reference-lines [3]. The INS- as well as the AW2000 background values are based on soil concentrations from relatively unpolluted natural areas in the Netherlands. However, both are based on a different dataset of measurements at different locations and derived using different methodologies. Therefore, some AW2000 values (including that for arsenic) are lower than their equivalent INS value. Both values are expressed on the basis of total As-concentrations in soil, normalised to 10% organic matter. For the recently new proposed value(17 mg/kg_{dwt}) [20], normalisation to organic matter has not been applied anymore. For the future it is expected that this value will be used in the Dutch soil policy, it is however unknown when this value will be implemented.

It should be noted that these background concentrations are based on soil analysis performed with severe extraction methods (e.g. aqua regia) supposed to extract the total metal content of the soil. Ecological risk

[1] For this alternative correction the following formula is used: $C_s = C_f\ (C_b/C_{b,f})$ where C_s is the normalised concentration of a field sample, C_f is the measured concentration, C_b is a concentration calculated with $C_b = ß_0 + ß_1L + 2.5ε$ using L=25 wt-% lutum and for arsenic $ß_0$=3.72; $ß_1$=0.207; ε=2.93, and $C_{b,f}$ is a concentration calculated with the same equation but for L the actual lutum fraction of the field sample is used.

limits including these background concentration should therefore only be compared to monitoring data obtained with similar methods. These risk limits should not be compared to monitoring data determined with softer extraction methods like $CaCl_2$ or HNO_3 extraction that are supposed to represent readily available or potentially available metal fractions.

1.5 Derivation of new risk limits

The derivation of ecological risk limits basically follows a four step approach: collection of literature, evaluation of the scientific reliability, selection of relevant endpoints and using the endpoints to derive the risk limits. It can be imagined that if new data were generated since the last evaluation, this may potentially lead to a different result. However, even if this is not the case and the same literature data would be used, newly derived risk limits will differ from those derived in 2001. Re-evaluation of the literature according to current insights may lead to different conclusions regarding the quality of the data, and the way risk limits are derived given a certain dataset has been adapted in several ways during the past years. A more detailed description of the methodology followed is given in chapter 3.

1.6 Readers guide

In the present report, new literature published after the report of 2001 was collected and assessed. In Chapter 2, the environmental characteristics of arsenic are given. In Chapter 3, the methodology is described and ecotoxicity endpoints for arsenic are presented in Chapter 4. The derivation of the risk limits is described in Chapter 5, and the conclusion is presented in Chapter 6.

2 Characteristics of arsenic

The ERLs for arsenic have been derived for aerobic soils. The most relevant species of arsenic are As(III) and As(V) but also As(0) and As(-III) are present in the environment [21]. In these oxidation states it forms a large variety of arsenic salts and organo-arsenic compounds [22]. As(V) is the predominant form of As in aerobic conditions. Generally, As(III) is formed under anaerobic conditions but it should be noted that also under aerobic conditions, As (III) can be formed by microbial processes [23]. As(III) is known to be more toxic than As(V) [24].

Specific physico-chemical properties of arsenic in general (CAS number: 7440-38-2) are not available. These details could be available for the specific arsenic salts but are not needed for the purpose of this report and are therefore not presented.
The following information has been taken over from the HSDB (Hazardous Substances Data Bank) record on Arsenic [25]:

"Arsenic is the 20th most abundant element in the earth's crust. It occurs most often as a compound with sulfide in a variety of complex minerals. Other important natural sources of arsenic in the environment are from volcanic eruptions. From the mid-19th century to 1940s, inorganic arsenic compounds were the dominant pesticides available to farmers and fruit growers. Around the 1960s, the use of inorganic arsenic compounds in agriculture disappeared. However, some arsenic pesticides are still used today. The production and use of arsenic compounds as wood preservatives (e.g., chrome copper arsenate) and pesticides (e.g., cacodylic acid) will result in its direct release to the environment. Arsenic's production and use in nonferrous alloys and in the manufacture of semiconductors may result in its release to the environment through various waste streams. Other important anthropogenic sources of arsenic in the environment are metal smelting and coal burning. In air, arsenic is present mainly in particulate form as arsenic trioxide. Arsenic compounds in the particulate phase may be removed from the air by wet and dry deposition. In water, inorganic species of arsenic occur mainly as As(V) in oxidizing environments such as surface water and As(III) under reducing conditions in groundwater. Soluble forms of arsenic move with water and may be carried long distances. However, arsenic strongly sorbs onto sediments. In acidic and neutral waters, As(V) is extensively adsorbed, while As(III) is relatively weakly adsorbed. In waters with a high pH, both oxidation states are relatively weakly adsorbed. Sorbed As(V) in sediments may be remobilized if conditions become sufficiently reduced for As(V) to form As(III). Arsenic compounds are methylated by bacteria and fungi to yield dimethyl and trimethylarsines. Methylation is important in the transfer of arsenic from the sediment to the water to the atmosphere. In soils, the mobility of arsenic in clay soils is low to moderate but much higher for loamy and sandy soils. The max adsorption of As(V) on kaolinite and montmorillonite is pH 5; sorption of As(III) increases beyond this pH and at pH 8 more As(III) is sorbed than As(V). At high pH, both oxidation states of arsenic will be more mobile in soil. The

potential for volatilization of arsenic compounds from moist surfaces varies greatly. Dissociated arsenic compounds may be sorbed by soil or may form strong complexes in solution. These arsenic compounds are not expected to volatilize from moist soil surfaces. However, arsenic compounds in soil may be methylated by microorganisms and subsequently lost by volatilization."

3 Methodology

3.1 Added risk approach

In the added risk approach [26] toxic effects from arsenic naturally present in the soil are excluded for the risk limit. In order to do so, the background concentration in the test soils in the experiments used to derive the ERLs, is neglected and is supposed not to contribute to the toxicity. Initially the ERLs are therefore derived on the basis of the amount added to the test soil. These ERLs are therefore referred to as Maximum Permissible Addition (MPA), Serious Risk Addition (SRA) and Intermediate ecological addition. In order to compare these values to field concentrations, the background concentration (Cb) is added to the MPA and SRA (MPC_{eco} = MPA + Cb, SRC_{eco} = SRA + Cb and Intermediate ecological concentration = Intermediate ecological addition + Cb). A generic Cb is used to derive general ERLs.
It should be noted that the field concentrations should be determined with the same analytical methodology as used for the background concentrations (see also Section 1.4).
It has been noted that the derivation of risk limits for metals should be performed with the total risk approach as is also the case in the water framework directive [27]. Following this approach, the total concentration in the test soil, e.g. the metal concentration originally present in the test soil and the added concentration together, should be considered for the ERLs. When this would result in risk limits lower than the natural background concentration, the added risk approach should be followed. Therefore at first the total risk approach is examined in Chapter 5, and thereafter the added risk approach.

3.2 Data collection and evaluation

An online literature search was performed on SCOPUS for publications published after derivation of the former ERL in 1997, the search profile is given in Appendix 1. This profile was run in June 2014. The total search resulted in approximately 1250 references, of which more than 50 references were considered relevant.
Where possible, the studies used in the previous risk derivation were also reassessed. Two of these studies (BKH, 1995, source of the endpoint for *Eisenia fetida* and Tyler, 1981 source for phosphatase endpoints) could not be retrieved and have not been included in the dataset. The study that was source of two endpoints for plants [28] only gave soil concentrations in mg/ha, for the previous ERL derivation these concentrations were recalculated into a concentration in soil, assuming a standard depth and soil bulk density. This recalculation is not considered acceptable anymore and the study is not used in this report. The remaining two studies [29,30] contained endpoints for soil processes and have been taken up in Appendix 2. The endpoints from these studies are all unbound values ("smaller than" or "greater than").

3.2.1 Data quality

Regarding data quality, a general observation is that the evaluation of the scientific reliability of individual ecotoxicity studies has received increasing attention over the years. This is partly due to the fact that more established test guidelines have become available, including criteria that can be used to (in)validate test results. It has to be noted, though, that aquatic data seem to be more often rejected than terrestrial tests when studies are re-evaluated according to current insights. This may be due to the fact that for some compounds maintenance of exposure concentrations in aquatic tests is more critical than in confined terrestrial test systems. Both the MPC_{eco} and the SRC_{eco} are preferably based on terrestrial ecotoxicity data. However, when such data are limited or absent, aquatic data may be used to derive risk limits for soil by using equilibrium partitioning. Changes in the quality assessment of aquatic data may thus be important for terrestrial risk limits as well. However, this is not relevant for arsenic since enough data from terrestrial ecotoxicity studies are available.

3.2.2 *Selection criteria*

In general, selection criteria as given in the guidance [16] are followed. Only for soil types it was considered in line with the derivation of risk limits for nickel [31,32], if the tests were performed with soils relevant for Europe. Therefore the following criteria were used:

- Only test results with natural or artificial soils were selected. Tests with other substrates, for instance agar agar, nutrient solutions, pure quartz sand or manure were excluded.
- Soils outside the range of 0.5-15% organic matter were excluded [33]. This also includes soils from deeper soil layers because they have a low organic matter content, and muck or peaty soils because of their high organic matter content.
- Soils described as paddy or volcanic are considered not relevant [33].

Also in line with the re-evaluation of the risk limits for nickel [31,32] which is performed at the same time as arsenic, the site of origin of soil and basic soil variables were generally not used as sole exclusion parameters.

3.2.3 *Data treatment*

Once reliable and relevant ecotoxicity endpoints are selected, the available data can be used in different ways to derive risk limits. If the number of data is limited, an assessment factor is put on the lowest endpoint. If more data are available, statistical extrapolation using Species Sensitivity Distributions (SSDs) can be applied. Changes in the requirements for using the latter were identified as an important factor when considering the uncertainty related to the previously derived risk limits [10]. An SSD displays the fraction of species potentially affected as a function of the exposure concentration. The Hazardous Concentration for 5% and 50% of the species (HC5 and HC50), are used as input for the MPC_{eco} and SRC_{eco}, respectively.
In 2001, SSDs were applied when data for at least four taxonomic groups were available[2], regardless of the trophic levels represented in the dataset. The HC5 and HC50 were used without any additional assessment factors. With the implementation of the European Technical

[2] e.g. bacteria, fungi, insects and earthworms

Guidance Document (TGD) for risk assessment of new and existing substances in 2003 [13], the requirements for performing SSDs have been extended. At present, SSDs can only be performed when at least 10 (preferably 15) values are available for at least eight different taxonomic groups, representing primary producers, and primary and secondary consumers. For the aquatic compartment, it is specified in detail which are the required taxonomic groups. This is not the case for soil, but the requirements with respect to the number of data and the inclusion of at least three trophic levels are considered to be the same. As a consequence, application of SSDs for terrestrial species is nowadays possible in rare cases only.
For the SRC_{eco}, whether or not performing an SSD, it is not a major change if No Observed Effect Concentrations (NOECs) are present for at least two trophic levels. The 50th percentile of the SSD that was used previously, is equal to the geometric mean of the NOECs that will be used now. However, when less than two taxonomic groups are present and/or the NOECs represent a single trophic level, acute data will be considered as well and an additional comparison with the equilibrium partitioning method will be made. In 2001, the comparison with equilibrium partitioning based values was almost always made and the lower value was chosen.
Secondary poisoning of birds and mammals ($MPC_{soil, secpois}$) has not been examined since secondary poisoning by consumption of worms is considered unlikely. Consumption of arsenic accumulating plants is however a potential route of exposure. This route has not been assessed because relevant guidance is not available.

4 Ecotoxicological data

4.1 Soil ecotoxicity data on arsenic

Selected soil ecotoxicity data are given in Table 2 to Table 7; details on these endpoints are tabulated in Appendix 1.
At first chronic endpoints based on total concentrations (based on measured concentrations or calculated as the original concentration in the test soil together with the nominal added concentration) are given in Table 2 and Table 3 for as far available in the data set. For acute tests no total concentrations were available. Endpoints based on added concentrations are given in Table 4 to Table 7. As stated in Chapter 2, the most relevant species of arsenic are As(III) and As(V). Since the proposed ERLs is for aerobic soils and As(V) is the predominant form of As in aerobic conditions while As(III) is formed under anaerobic conditions, endpoints for As(III) and As(V) are presented separately.
In contrast to organic compounds, it is recommended not to normalise the results of terrestrial metal toxicity experiments to a standard soil, because even after normalisation, soil properties can influence the outcome of the experiment [16]. Therefore, for all soils it was considered if they were relevant for Europe (see also Section 3.2.2).
Also for arsenic the very complex soil chemistry hampers performing a normalisation. For this reason, individual toxicity results for one species or process with the same endpoint determined in different soils are not averaged, but the lowest value is selected. In some cases soils were aged after the addition of the test compound before initiating the test. Since the extent of the ageing process in different soils is unknown, ageing is considered as a different test condition and test results from a soil determined after ageing are not averaged with results from the same soil without ageing. Unbound values (greater or smaller than) are not used for ERL derivation. When these are the only value available for a species, these are presented in the tables below as indication.

Table 2. Aggregated total chronic toxicity data for As (V) to soil organisms.

Taxonomic group	NOEC/EC10 (mg As/kg$_{dwt}$)	Reason for selection	Ref.
Annelida			
Lumbricus rubellus	28.5	most sensitive endpoint: growth (biomass) and population growth	[34]
Macrophyta			
Lactuca sativa	78.6	lowest endpoint from a test with 6 different soils	[35]
Pisum sativum	5.56	most sensitive endpoint: growth (length of both shoot and root)	[36]
Pteris vittata	<109		[37]
Triticum aestivum	51.8	lowest fixed endpoint	[38]

Table 3. Aggregated total chronic toxicity data for As (III) to soil organisms.

Taxonomic group	NOEC/EC10 (mg As/kg_{dwt})	Reason for selection	Ref.
Macrophyta			
Lycopersicon esculentum	16.1	most sensitive endpoint: growth (leaf weight)	[39]

Table 4. Aggregated added acute toxicity data for As (V) to soil organisms.

Taxonomic group	L(E)C50 (mg As/kg_{dwt})	Reason for selection	Ref.
Macrophyta			
Hordeum vulgare	26.6	lowest endpoint from a test with 16 different soils	[40]
Lactuca sativa	59.3	lowest endpoint from a test with 6 different soils	[35]
Triticum aestivum	159	lowest endpoint from a test with 5 different soils performed for 6 days	[35]
Annelida			
Eisenia fetida	21.7	only available endpoint for As(V)	[41]
Lumbricus terrestris	100	value for 10 days exposure, lowest value when endpoints for different sand layers from the same location are combined.	[42]
Soil processes			
DMSO reduction	4370		[43]
Sulphatase	712	lowest value for loamy sand	[43]
Urease activity	>37.5		[30]

Table 5. Aggregated added acute toxicity data for As (III) to soil organisms.

Taxonomic group	L(E)C50 (mg As/kg_{dwt})	Reason for selection	Ref.
Annelida			
Eisenia fetida	10.9		[41]
Soil processes			
Urease activity	<37.5		[30]

Table 6. Aggregated added chronic toxicity data for As (V) to soil organisms.

Taxonomic group	NOEC/EC10 (mg As/kg_{dwt})	Reason for selection	Ref.
Insecta			
Folsomia candida	0.74	most sensitive endpoint: reproduction	[44]
Annelida			
Dendrodrilus rubidus	<494		[45]
Eisenia fetida	1.87	most sensitive endpoint: growth (body weight)	[46]
Enchytraeus albidus	10		[47]
Lumbricus rubellus	12	most sensitive endpoint: growth (biomass) and population growth	[34]
Macrophyta			
Lactuca sativa	2.6	lowest endpoint from a test with 11 different soils	[48]
Pisum sativum	5	most sensitive endpoint: growth (length of both shoot and root)	[36]
Pteris vittata	<100		[37]
Solanum tuberosum	30	most sensitive endpoint: growth (leaf area)	[49]
Triticum aestivum	50	most sensitive endpoint: growth (biomass)	[38]
Soil processes			
Active microbial biomass carbon	0.17	endpoint for vertisol	[50]
Active microbial biomass carbon	0.0033	endpoint for inceptisol	[50]
Active microbial biomass carbon	0.13	endpoint for entisol	[50]
Basal soil respiration	0.28	endpoint for vertisol	[50]
Basal soil respiration	0.0068	endpoint for inceptisol	[50]
Basal soil respiration	6.4	endpoint for entisol	[50]
Dehydrogenase activity	0.96	endpoint for vertisol	[50]
Dehydrogenase activity	6.8	endpoint for inceptisol	[50]
Dehydrogenase activity	0.92	endpoint for entisol	[50]
FDA-hydrolase	0.75	endpoint for vertisol	[50]
FDA-hydrolase	0.40	endpoint for inceptisol	[50]
FDA-hydrolase	0.0059	endpoint for entisol	[50]
Microbial biomass carbon	116	endpoint for vertisol	[50]
Microbial biomass carbon	0.017	endpoint for inceptisol	[50]

Taxonomic group	NOEC/EC10 (mg As/kg_{dwt})	Reason for selection	Ref.
Microbial biomass carbon	5.6	endpoint for entisol	[50]
Nitrogen mineralisation	<1.13	endpoint in three different soils: loam, silty clay and clay loam	[29]

Table 7. Aggregated added chronic toxicity data for As (III) to soil organisms.

Taxonomic group	NOEC/EC10 (mg As/kg_{dwt})	Reason for selection	Ref.
Annelida			
Eisenia fetida	1.87	most sensitive endpoint: growth (body weight)	[41]
Macrophyta			
Acacia mangium	14.3	most sensitive endpoint: growth (root weight)	[51]
Lycopersicon esculentum	15	most sensitive endpoint: growth (leaf weight)	[39]
Mimosa caesalpiniaefolia	32.2		[51]
Soil processes			
Nitrogen mineralisation	<1.13		[29]

5 Derivation of ERLs

5.1 Difference in toxicity between As(III) and As(V)

The required ERLs for which this report is written are for aerobic soils. As indicated in Chapter 2, the main species present under oxidising conditions is As(V). As(III) is more toxic [24] but generally formed under reducing conditions and therefore supposed to be limited available in aerobic soils. All selected endpoints are for tests performed under aerobic conditions but in these test As(III) and (As(V) were tested. No analysis was performed to determine the actual oxidation state of the As during the test but it could be presumed that under aerobic conditions, most As(III) is quickly oxidised into As(V). To confirm this presumption, it is at first investigated if there is a significant difference in the toxicity endpoints from studies performed with As(V) or As(III). When there is no significant difference it can be presumed that the endpoints are representative for an aerobic soil with mainly As(V) present.
In the acute dataset for As(III) only one endpoint is available, this endpoint is for *Eisenia fetida* and originates from a study [41] in which As(V) was also tested. Although this study showed a significant difference between As(III) and As(V) for the burrowing time, statistic for the LC50 were not given and it was only stated that the observed difference indicated that As(III) was more toxic than As(V). This is the only endpoint for As(III) and the acute dataset does not provide enough data to conclude that As(III) would have a different acute toxicity than As(V). The chronic added dataset does contain eight unbound endpoints for As(V) and four for As(III). These values are in the same order of magnitude and do not differ significantly ($p = 0.86$). Also the endpoint in the dataset with endpoints based on total concentrations the endpoints for AS(V) and As(III) are in the same order of magnitude. On the basis of the available data, it is therefore considered unrealistic to exclude the endpoints from test performed with As(III) for the derivation of the ERLs for aerobic soils. Therefore, the endpoints for As(V) and As(III) will be pooled for the derivation of the ERLs.

5.2 Derivation of the $MPC_{soil, eco}$ with the total risk approach

The chronic endpoints based on total concentrations as given in Table 2 and Table 3 are for one annelida and four macrophyta. Therefore only the assessment factor method can be applied. With endpoints for two trophic levels an assessment factor of 50 is applied to the lowest value of 5.6 mg/kg for *Pisum sativum*. This results in an MPC of 0.11 mg/kg. This value is lower than any of the background concentrations for arsenic as given in Section 1.4. Therefore the total risk approach is considered not appropriate since it overestimates potential effects and the risk limits should be derived with the added risk approach.

5.3 Derivation of the $MPA_{soil, eco}$

The MPA can be derived using statistical extrapolation (SSD) or with the assessment factor method. The INS-guidance [16] indicates that for soil at least endpoints for 10 species from different taxonomic groups should be available. Our chronic dataset contains endpoints for 10 different

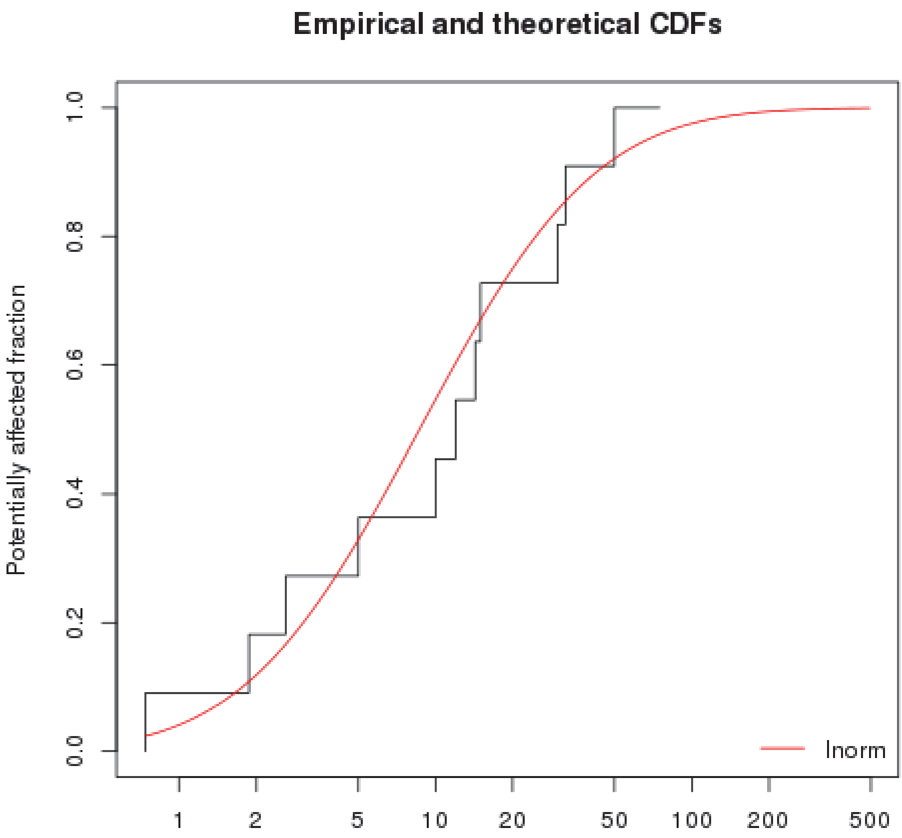
species (including the unbound endpoints). Therefore the SSD method is also applied.
In the ERL derivation, endpoints for individual species should be kept separated from those for soil processes because the latter are based on a whole population of micro-organisms. As can be seen from Table 6, endpoints for five different processes are available. These processes are however very different in nature. E.g. it is unknown how microbial biomass carbon relates to FDA-hydrolase. It is therefore considered unrealistic to use the values for these different endpoints into one SSD and the MPA for processes is only derived by means of the assessment factor method.

5.3.1 Assessment factor method

For species, chronic soil toxicity data are available for producers (*macrophyta*) and primary consumers (*insects* and *annelida*). With chronic data for individual species representing three trophic levels, an assessment factor of 10 can be applied to lowest species value of 0.74 mg/kg_{dwt}. This results in an $MPA_{soil,\ eco}$ of 0.074 mg/kg_{dwt} for species.
Bounded endpoints for three different soil processes are available, this is considered sufficient to apply an assessment factor of 10 to the lowest endpoint (0.0033 mg As/kg) for processes. This results in a process $MPA_{soil,\ eco}$ of 0.00033 mg/kg_{dwt} for processes.

5.3.2 SSD method

Statistical extrapolation was performed with the endpoints for the individual species. In performing a statistical extrapolation, it is possible to include unbound endpoints using the program MOSAIC-SSD [52]. The SSD is presented in Figure 1 and the HC5 is calculated as 1.12 mg/ kg_{dwt} with a 95% confidence interval of 0.42 to 5.28 mg/ kg_{dwt}. Because the dataset contains the minimum number of data and includes unbound values, an assessment factor of 5 is applied to the HC5 value, leading to an $MPA_{soil,\ eco}$ for individual species of 0.22 mg/ kg_{dwt}. This value is a factor of three higher than that derived with the assessment factor method.



Concentration in mg/kg$_{dwt}$ (log scale)

Figure 1 Species Sensitivity Distribution for Arsenic based on chronic endpoints for individual species. The X-axis represents the concentration in soil in mg/kg$_{dwt}$ on a log-scale, the Y-axis represents that fraction of species potentially affected above their NOEC- or EC10-value.

For the processes, the statistical extrapolation can also be followed. In this approach every available endpoint for each soil tested will be used in the SSD. Since unbounded values are also available, the program MOSAIC-SSD [52] is used here too. The SSD is presented in Figure 2 and the HC5 is calculated as 0.0024 mg/ kg$_{dwt}$ with a 95% confidence interval of 0.0005 to 0.025 mg/ kg$_{dwt}$. Because the dataset for soil processes is quite extensive, an assessment factor of 2 is applied to the HC5 value, leading to an MPA$_{soil, eco}$ for individual species of 0.0012 mg/ kg$_{dwt}$. This value is a factor of 36 higher than that derived with the assessment factor method.

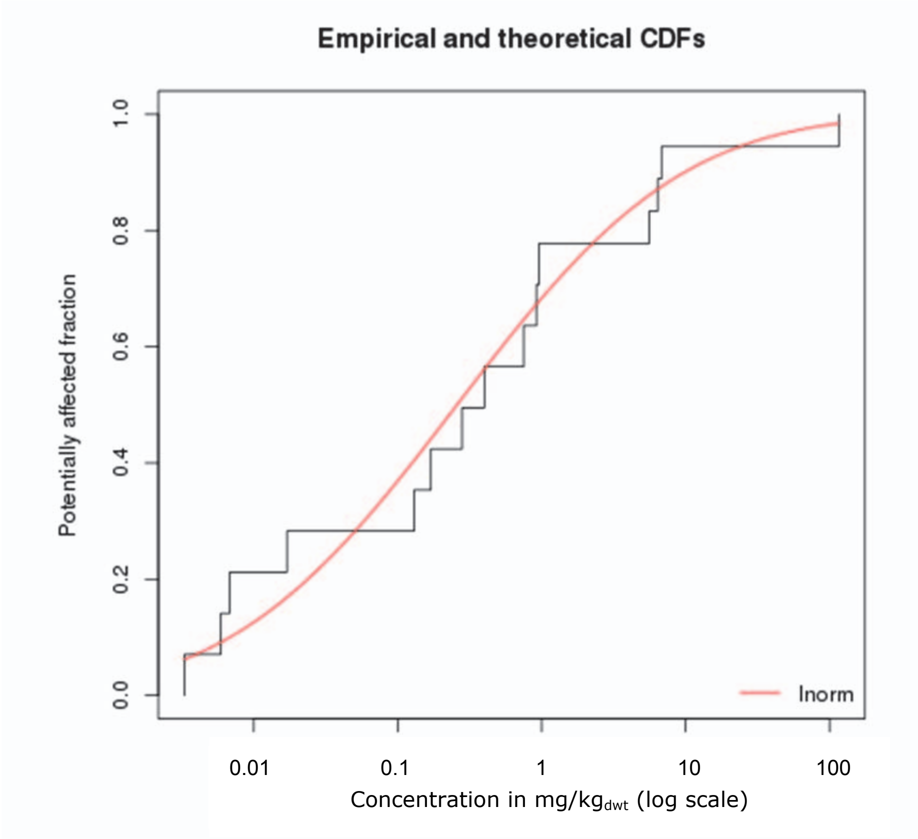


Figure 2 Species Sensitivity Distribution for Arsenic based on endpoints for soil processes. The X-axis represents the concentration in soil in mg/kg$_{dwt}$ on a log-scale, the Y-axis represents that fraction of species potentially affected above their NOEC- or EC10-value.

5.3.3 *Selection of the MPA$_{soil, eco}$ and calculation of the MPC$_{soil, eco}$*

For individual species, values for the MPA$_{soil, eco}$ have been calculated with the assessment factor method and the SSD method. Both values differ by a factor three. Since the SSD method involves the whole dataset and it does optically show a good fit, it is preferred over the assessment factor method. Therefore, the MPA$_{soil, eco}$ for individual species is 0.22 mg/kg$_{dwt}$. Similarly the endpoint for processes based on the SSD method is preferred over that derived with the assessment factor method. The selected MPA$_{soil, eco}$ for processes is therefore 0.0012 mg/kg$_{dwt}$. This value more than a factor of 100 lower than that for the individual species.
It has been noted that the endpoints for the soil processes originate from only two studies. These studies have been performed at a relatively high temperature of 28 and 30°C. It is unclear if soil processes are affected by this temperature but in general bacterial processes perform well at this temperature. Furthermore, the publication from Prasad et al. [50] presents figures where a clear concentrations effect relation can be observed. Since there is no reason to invalidate the endpoints from this study cannot be omitted from the dataset and the MPA$_{soil, eco}$ for processes being the lowest will set the final MPA$_{soil, eco}$: 0.0012 mg/kg$_{dwt}$.

The $MPA_{soil, eco}$ selected is a factor 750 lower than the current MPA (0.9 mg/kg_{dwt}), this difference is caused because the new value is based on a more extensive dataset which includes very sensitive endpoint for soil processes but also because the old MPA was normalised to soil with 10% organic matter.

For a risk assessment or interpretation of monitoring values, the MPA should be added to the natural background concentration. However, because the $MPA_{soil, eco}$ is relatively small as compared to the background concentration, the $MPC_{soil, eco}$ will be equal to the background concentration. The MPC is applicable to soils under aerobic conditions.

It should be noted that the $MPA_{soil, eco}$ is only based on direct toxicity and secondary poisoning is not considered in this ERL.

5.4 Derivation of the $SRA_{soil, eco}$

It has been preferred to apply the added risk approach because this was also done for the derivation of the $MPC_{soil, eco}$ and the dataset for the added risk approach is much more extensive and includes data for more sensitive species. The $SRA_{soil, eco}$ is calculated as the geometric mean of the chronic toxicity data or the HC50 from the SSD method.
Theoretically these values would be equal, but since in the SSD method unbound values can be used, the outcome could be different. Because unbound values are used in the SSD method for species, data for more species are included in the HC50 and preference is given to this value. The HC50 of all chronic endpoints for species (Table 6) is 8.67 mg/kg_{dwt}. This value is more than a factor of 5 lower than the current SRA (56 mg/kg_{dwt}), this difference is caused because the new value is based on a more extensive dataset but also because the old SRA was normalised to soil with 10% organic matter. Since the latter is not realistic for arsenic this normalisation is not applied anymore.
Since chronic endpoints for soil processes are also available for several soils, an SSD has been performed and the HC50 of these endpoints is calculated as 0.26 mg/kg_{dwt}. This value is more than a factor of 30 lower than the HC50 for individual species.
Soil processes can however not be ignored for the $SRA_{soil, eco}$. From the current available data it is expected that at the level of the HC50 for species, all soil processes will be affected. Even at the level of a HC50 derived from a combined dataset for soil processes and species (1.0 mg/kg_{dwt}) it is expected that more than 95% of all soil processes will be affected. Therefore the SRC for soil processes (0.26 mg/kg_{dwt}) is selected as the final $SRA_{soil, eco}$.

For a risk assessment or interpretation of monitoring values, the SRC should be added to the natural background concentration (Cb). The SRC is applicable to soils under aerobic conditions.

As noted above for the $MPA_{soil, eco}$, the $SRA_{soil, eco}$ is also only based on direct toxicity as secondary poisoning was not considered for this ERL.

5.5 Derivation of the Intermediate ecological addition

The Intermediate ecological addition, calculated as the HC20 of the SSD for soil processes is 0.024 mg/kg_{dwt} (the current value is 27 mg/kg). For a risk assessment or interpretation of monitoring values, the Intermediate ecological addition should be added to the natural background concentration (Cb).

5.6 Overview of current and new derived risk limits

For an impression of the differences between the current and the new derived risk limits, they are all given in Table 8.

Table 8. Summary of proposed ERLs for arsenic in soil.

Risk limit	**Current value [mg As/kg$_{dwt}$]**	**New value [mg As/kg$_{dwt}$]**
$MPA_{soil, eco}$	0.9	0.0012
$SRA_{soil, eco}$	56	0.26
Intermediate ecological addition	27	0.024
Background concentration (Cb) currently used in Dutch soil policy with soil type correction (see Section 1.4)	20	
Background concentration (Cb) derived according to the INS method (see Section 1.4)	29	
Revised background concentration (Cb) with alternative soil type correction (see Section 1.4)		17

6 Conclusions

In this report, the Maximum Permissible Addition ($MPA_{soil, eco}$), Serious Risk Addition ($SRA_{soil, eco}$) and an 'intermediate ecological addition' are derived for arsenic in soil ecosystems. Secondary poisoning of predators consuming terrestrial organisms has not been evaluated in this study. Secondary poisoning by consumption of worms is considered unlikely however consumption of arsenic accumulating plants is a potential route of exposure. This latter route has not been assessed because relevant guidance is not available and it is unknown if the derived ERLs are protective for this kind of exposure. The new ERLs are much lower than the current ERLs because a more extensive dataset has been used and because the values have not been normalised to organic matter. Furthermore studies on effects of arsenic on soil processes, which were not considered for the current risk limits, highly influenced the new risk limits since these processes are highly sensitive to the presence of arsenic. Nevertheless, the results of this report also indicate that the current ERLs are not protective for individual species. The proposed ERLs, summarised in the table below, are applicable to aerobic soils.

Table 9. Summary of proposed ERLs for arsenic in soil.

	Value [mg As/kg_{dwt}]
$MPA_{soil, eco}$	0.0012
$SRA_{soil, eco}$	0.26
Intermediate ecological addition	0.024
Background concentration (Cb) currently used in Dutch soil policy with soil type correction (see Section 1.4)	20
Revised background concentration (Cb) with alternative soil type correction (see Section 1.4)	17

References

1. Verbruggen EMJ, Posthumus R, Van Wezel AP. 2001. Ecotoxicological Serious Concentrations for soil, sediment and (ground)water: updated proposals for first series of compounds. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 711701020.
2. Crommentuijn T, Kalf DF, Polder MD, Posthumus R, Van de Plassche EJ. 1997. Maximum Permissible Concentrations and Negligible Concentrations for pesticides. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 601501002.
3. Crommentuijn T, Polder MD, Van de Plassche EJ. 1997. Maximum Permissible Concentrations and Negligible Concentrations for metals, taking background concentrations into account. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 601501001.
4. Denneman CAJ, Van Gestel CAM. 1990. Bodemverontreiniging en bodemecosystemen: voorstel voor C-(toetsings) waarden op basis van ecotoxicologische risico's. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 725201001.
5. Van de Meent D, Aldenberg T, Canton JH, Van Gestel CAM, Slooff W. 1990. STREVEN NAAR WAARDEN. Achtergrondstudie ten behoeve van de nota "Milieukwaliteitsnormering water en bodem'. Bilthoven, The Netherlands National Institute for Public Health and the Environment. Report no. 670101002.
6. Van de Plassche EJ. 1994. Towards integrated environmental quality objectives for several compounds with a potential for secondary poisoning. Bilthoven, The Netherlands: National Institute of Public Health and the Environment. Report no. 679101012.
7. Verbruggen EMJ. 2012. Environmental risk limits for polycyclic aromatic hydrocarbons (PAHs). For direct aquatic, benthic, and terrestrial toxicity. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 607711007.
8. Van Vlaardingen PLA, Posthumus R, Posthuma-Doodeman CJAM. 2005. Environmental Risk Limits for Nine Trace Elements. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 601501029.
9. Mesman M, Lijzen JPA. 2012. Discussienotitie normstelling ecologische risico's. Onderzoeksprogramma 2012-2014. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 607711008.
10. Brand E, Smit E, Verbruggen E, Dirven-Van Breemen L. 2013. Onderbouwing ecologische risicogrenswaarden voor bodem. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 607711012.
11. VROM. 1999. Environmental risk limits in the Netherlands. A review of environmental quality standards and their policy framework in the Netherlands. The Hague, The Netherlands, Ministry of Housing, Spatial Planning and the Environment.

12. VROM. 2004. (Inter)nationale Normen Stoffen. Den Haag, The Netherlands, Ministry of Housing, Spatial Planning and the Environment.
13. EC. 2003. Technical Guidance Document on risk assessment in support of Commission Directive 93/67/EEC on risk assessment for new notified substances, Commission Regulation (EC) No 1488/94 on risk assessment for existing substances and Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market. Ispra, Italy: European Commission Joint Research Centre.
14. ECHA. 2008. Guidance on information requirements and chemical safety assessment. Chapter R.10: Characterisation of dose [concentration]-response for environment. Helsinki, Finland: European Chemicals Agency.
15. ECHA. 2012. Guidance on information requirements and chemical safety assessment Chapter R.16: Environmental Exposure Estimation. Version 2.1. Helsinki, Finland: European Chemicals Agency.
16. Van Vlaardingen PLA, Verbruggen EM, J. 2007. Guidance for the derivation of environmental risk limits within the framework of "International and national environmental quality standards for substances in the Netherlands" (INS). Bilthoven, The Netherlands: National Institute for Public Health and the Environment (RIVM). Report no. 601782001.
17. Dirven-Van Breemen EM, Lijzen JPA, Otte PF, Van Vlaardingen PLA, Spijker J, Verbruggen EMJ, Swartjes FA, Groenenberg JE, Rutgers M. 2007. National land-use-specific reference values: a basis for maximum values in Dutch soil policy. Bilthoven, The Netherlands: National Institute for Public Health and the Environment. Report no. 711701053 (in Dutch).
18. Spijker J, Van Vlaardingen PLA. 2007. Implicaties van voorgestelde bodemnormwaarden uit 'Achtergrondwaarden 2000' in relatie tot risico's. Bilthoven: RIVM. Report no. 711701052.
19. VROM. 2008. NOBO: Normstelling en bodemkwaliteitsbeoordeling, Onderbouwing en beleidsmatige keuzes voor de bodemnormen in 2005, 2006 en 2007. The Hague, the Netherlands: Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieu. Report no. VROM no. 8395.
20. Spijker J. 2012. The Dutch Soil Type Correction : An alternative approach. Bilthoven: RIVM. Report no. 607711005.
21. O'Neill P. 1995. Arsenic. IN Alloway BJ (Ed.) Heavy metals in soils. 2nd ed. London, Blackie Academic and Professional.
22. Rahman MA, Hogan B, Duncan E, Doyle C, Krassoi R, Rahman MM, Naidu R, Lim RP, Maher W, Hassler C. 2014. Toxicityofarsenicspeciestothreefreshwaterorganisms and biotransformationofinorganicarsenicbyfreshwater phytoplankton(Chlorella sp. CE-35). Ecotoxicology and Environmental Safety. 106: 126-135.
23. Wenzel WW. 2013. Arsenic. IN Alloway BJ (Ed.) Heavy metals in soil - trace metals and metallooids in soil and their biovailability. 3th ed. Dordrecht, Springer Science+Business Media.
24. Reddy R, DeLaune RD. 2008. Biogeochemistry of wetlands: science and applications, Boca Raton, USA, CRC press, Taylor & Francis Group.

25. TOXNET. 2014. HSDB record on arsenic compounds. Bethesda, USA, U.S. National Library of Medicine.
26. Crommentuijn T, Polder MD, Sijm D, De Bruijn J, Van de Plassche EJ. 2000. Evaluation of the Dutch environmental risk limits for metals by application of the added risk approach. Environmental Toxicology and Chemistry. 19: 1692-1701.
27. EC. 2011. Technical guidance for deriving environmental quality standards. Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 27. Brussels: European Communities.
28. Deuel LE, Swoboda AR. 1972. Arsenic toxicity to cotton and soybeans. J.Environ.Quality. 1: 317-320.
29. Liang CN, Tabatabai MA. 1977. Effects of trace elements on nitrogen mineralisation in soils. Environ.Pollut. 12: 141-147.
30. Tabatabai MA. 1977. Effect of trace elements on urease activity in soils. Soil.Biol.Biochem. 9: 9-13.
31. Verschoor AJ. draft. Update of ecological risk limits of nickel in soil. Bilthoven: RIVM.
32. Denmark. 2008. European Union risk assessment report. Nickel and nickel compounds. Prepared by The Danish Environmental Protection Agency, on behalf of the European Union,Retrieved from: (http://eng.mst.dk/topics/chemicals/nickel)
33. Mensink BJWG, Smit CE, Montforts MHMM. 2008. Manual for summarising and evaluating environmental aspects of plant protection products. Bilthoven: RIVM. Report no. 601712004.
34. Anderson CJ, Kille P, Lawlor AJ, Spurgeon DJ. 2013. Life-history effects of arsenic toxicity in clades of the earthworm *Lumbricus rubellus*. Environmental Pollution. 172: 200-207.
35. Cao Q, Hu QH, Baisch C, Khan S, Zhu YG. 2009. Arsenate toxicity for wheat and lettuce in six chinese soils with different properties. Environmental Toxicology and Chemistry. 28: 1946-1950.
36. Päivöke AEA, Simola LK. 2001. Arsenate toxicity to *Pisum sativum*: Mineral nutrients, chlorophyll content, and phytase activity. Ecotoxicology and Environmental Safety. 49: 111-121.
37. Li WX, Chen TB, Huang ZC, Lei M, Liao XY. 2006. Effect of arsenic on chloroplast ultrastructure and calcium distribution in arsenic hyperaccumulator *Pteris vittata* L. Chemosphere. 62: 803-809.
38. Zhang WD, Liu DS, Tian JC, He FL. 2009. Toxicity and accumulation of arsenic in wheat (*Triticum aestivum* L.) varieties of China. Phyton. 78: 147-154.
39. Miteva E. 2002. Accumulation and effect of arsenic on tomatoes. Communications in Soil Science and Plant Analysis. 33: 1917-1926.
40. Song J, Zhao FJ, McGrath SP, Luo YM. 2006. Influence of soil properties and aging on arsenic phytotoxicity. Environmental Toxicology and Chemistry. 25: 1663-1670.
41. Lee BT, Kim KW. 2013. Toxicokinetics and Biotransformation of As(III) and As(V) in *Eisenia fetida*. Human and Ecological Risk Assessment. 19: 792-806.
42. Meharg AA, Shore RF, Broadgate K. 1998. Edaphic factors affecting the toxicity and accumulation of arsenate in the

earthworm *Lumbricus terrestris*. Environmental Toxicology and Chemistry. 17: 1124-1131.
43. Speir TW, Kettles HA, Parshotam A, Searle PL, Vlaar LNC. 1999. Simple kinetic approach to determine the toxicity of As[V] to soil biological properties. Soil Biology and Biochemistry. 31: 705-713.
44. Crouau Y, Moïa C. 2006. The relative sensitivity of growth and reproduction in the springtail, *Folsomia candida*, exposed to xenobiotics in the laboratory: An indicator of soil toxicity. Ecotoxicology and Environmental Safety. 64: 115-121.
45. Langdon CJ, Piearce TG, Meharg AA, Semple KT. 2001. Survival and behaviour of the earthworms *Lumbricus rubellus* and *Dendrodrilus rubidus* from arsenate-contaminated and non-contaminated sites. Soil Biology and Biochemistry. 33: 1239-1244.
46. Lee BT, Kim KW. 2009. Lysosomal membrane response of earthworm, *Eisenia fetida*, to arsenic contamination in soils. Environmental Toxicology. 24: 369-376.
47. Lock K, Janssen CR. 2002. Toxicity of arsenate to the compostworm *Eisenia fetida*, the potworm *Enchytraeus albidus* and the springtail *Folsomia candida*. Bulletin of Environmental Contamination and Toxicology. 68: 760-765.
48. Koo N, Jo HJ, Lee SH, Kim JG. 2011. Using response surface methodology to assess the effects of iron and spent mushroom substrate on arsenic phytotoxicity in lettuce (*Lactuca sativa* L.). Journal of Hazardous Materials. 192: 381-387.
49. Jůzl M, Štefl M. 2002. The effect of leaf area index on potatoes yield in soils contaminated by some heavy metals. Rostlinna Vyroba. 48: 298-306.
50. Prasad P, George J, Masto RE, Rout TK, Ram LC, Selvi VA. 2013. Evaluation of Microbial Biomass and Activity in Different Soils Exposed to Increasing Level of Arsenic Pollution: A Laboratory Study. Soil and Sediment Contamination. 22: 483-497.
51. Cipriani HN, Dias LE, Costa MD, Campos NV, Azevedo AA, Gomes RJ, Fialho IF, Amezquita SPM. 2013. Arsenic toxicity in *Acacia mangium* Willd. and *Mimosa caesalpiniaefolia* Benth. seedlings. Revista Brasileira de Ciencia do Solo. 37: 1423-1430.
52. MOSAIC. 2014. Modeling and Statistical tools for ecotoxicology (computer program). Version Lyon, France, Biometry and Evolutionary Biology Laboratory (UMR CNRS 5558) of University Lyon 1.
53. Welp G. 1999. Inhibitory effects of the total and water-soluble concentrations of nine different metals on the dehydrogenase activity of a loess soil. Biology and Fertility of Soils. 30: 132-139.
54. Langdon CJ, Piearce TG, Black S, Semple KT. 1999. Resistance to arsenic-toxicity in a population of the earthworm *Lumbricus rubellus*. Soil Biology and Biochemistry. 31: 1963-1967.
55. Sinha S, Sinam G, Mishra RK, Mallick S. 2010. Metal accumulation, growth, antioxidants and oil yield of *Brassica juncea* L. exposed to different metals. Ecotoxicology and Environmental Safety. 73: 1352-1361.
56. Cox MS, Kovar JL. 2001. Soil arsenic effects on canola seedling growth and ion uptake. Communications in Soil Science and Plant Analysis. 32: 107-117.

57. Cox MS, Bell PF, Kovar JL. 1996. Differential tolerance of canola to arsenic when grown hydroponically or in soil. Journal of Plant Nutrition. 19: 1599-1610.
58. Srivastava S, Singh N. 2014. Mitigation approach of arsenic toxicity in chickpea grown in arsenic amended soil with arsenic tolerant plant growth promoting *Acinetobacter* sp. Ecological Engineering. 70: 146-153.
59. Anderson RH, Basta NT, Lanno RP. 2008. Partitioning species variability from soil property effects on phytotoxicity: ECx normalization using a plant contaminant sensitivity index. Journal of Environmental Quality. 37: 1701-1709.
60. Arriagada C, Aranda E, Sampedro I, Garcia-Romera I, Ocampo JA. 2009. Contribution of the saprobic fungi *Trametes versicolor* and *Trichoderma harzianum* and the arbuscular mycorrhizal fungi *Glomus deserticola* and *G. claroideum* to arsenic tolerance of *Eucalyptus globulus*. Bioresource Technology. 100: 6250-6257.
61. Titah HS, Sheikh Abdullah SR, Idris M, Anuar N, Basri H, Mukhlisin M. 2012. Arsenic range finding phytotoxicity test against *Ludwigia octovalvis* as first step in phytoremediation. Research Journal of Environmental Toxicology. 6: 151-159.
62. Titah HS, Abdullah SRS, Mushrifah I, Anuar N, Basri H, Mukhlisin M. 2013. Arsenic toxicity on *Ludwigia octovalvis* in spiked Sand. Bulletin of Environmental Contamination and Toxicology. 90: 714-719.
63. Miteva E, Hristova D, Nenova V, Maneva S. 2005. Arsenic as a factor affecting virus infection in tomato plants: Changes in plant growth, peroxidase activity and chloroplast pigments. Scientia Horticulturae. 105: 343-358.
64. Das I, Ghosh K, Das DK, Sanya SK. 2013. Assessment of arsenic toxicity in rice plants in areas of West Bengal. Chemical Speciation and Bioavailability. 25: 201-208.
65. Lee CH, Huang HH, Syu CH, Lin TH, Lee DY. 2014. Increase of As release and phytotoxicity to rice seedlings in as-contaminated paddy soils by Si fertilizer application. Journal of Hazardous Materials. 276: 253-261.
66. Marques APGC, Rangel AOSS, Castro PML. 2007. Effect of arsenic, lead and zinc on seed germination and plant growth in black nightshade (*Solanum nigrum* L.) vs. clover (*Trifolium incarnatum* L.). Fresenius Environmental Bulletin. 16: 896-903.
67. Nanda S, Abraham J. 2011. Impact of heavy metals on the rhizosphere microflora of Jatropha multifida and their effective remediation. African Journal of Biotechnology. 10: 11948-11955.
68. Ke X, Sun Y, Zhang Y. 2013. Toxicity of As on soil neutral phosphatase. Applied Mechanics and Materials.

Appendix 1 - SCOPUS search profile

(TITLE-ABS-KEY(**arsenic** AND **toxicity** AND (**soil** OR **plant** OR **worm** OR *Allolobophora OR Arachis OR Avena OR Banksia OR Brassica OR Casuarina OR Chlorococcum OR Cucumis OR Dehydrogenase OR Eisenia OR Enchytraeus OR Eucalyptus OR Eudrilus OR Folsomia OR Glycine OR Helix OR Heterotrophic OR Hypoaspis OR Lactuca OR Lolium OR nitrification OR Oniscus OR Perionyx OR Phaseolus OR Porcellio OR Protaphorura OR respiration OR Respiration, OR Selenastrum OR Sinapsis OR Total OR Trifolium OR Triticum OR Vigna OR Zea*))) AND (PUBYEAR > **1996**)

Appendix 2 Detailed ecotoxicity data

Table A2.1 Acute toxicity of arsenic to soil organisms

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Criterion	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Macrophyta															
Hordeum vulgare	seedlings (1 day)	Vertic Cambisol, Italy	N	As (V)	5.4	1.48	51	20/16 d/n	4 d	EC50	root length	200.4	2	27,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Calcaric Cambisol, France	N	As (V)	7.5	2.57	50	20/16 d/n	4 d	EC50	root length	419.6	2	22,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Luvisol, Spain	N	As (V)	7.6	0.90	20	20/16 d/n	4 d	EC50	root length	44.9	2	29,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Calcic Cambisol, Spain	N	As (V)	7.5	0.65	25	20/16 d/n	4 d	EC50	root length	71.4	2	28,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Dystric Regosol, Sweden	N	As (V)	4.8	2.77	7	20/16 d/n	4 d	EC50	root length	46.1	2	30,48,4,83	[40]
Hordeum vulgare	seedlings (1 day)	Calcaric Fluvisol, NL	N	As (V)	7.5	2.16	26	20/16 d/n	4 d	EC50	root length	205	2	31,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Chromic Cambisol, France	N	As (V)	5.2	1.29	9	20/16 d/n	4 d	EC50	root length	28.5	2	19,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Eutric Cambisol, UK	N	As (V)	3.4	8.84	13	20/16 d/n	4 d	EC50	root length	35.7	2	36,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Histosol, UK	N	As (V)	4.2	22.00	13	20/16 d/n	4 d	EC50	root length	26.6	2	34,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Haplic Luvisol, France	N	As (V)	7.4	2.14	27	20/16 d/n	4 d	EC50	root length	115.1	2	20,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Chromic Luvisol, Greece	N	As (V)	4.8	0.70	38	20/16 d/n	4 d	EC50	root length	240.4	2	26,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Rendzic Leptosol, Greece	N	As (V)	7.4	4.44	46	20/16 d/n	4 d	EC50	root length	131.1	2	25,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Haplic Luvisol, Belgium	N	As (V)	6.8	1.67	15	20/16 d/n	4 d	EC50	root length	56.9	2	18,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Stagnic Luvisol, France	N	As (V)	7.3	2.50	38	20/16 d/n	4 d	EC50	root length	458.2	2	23,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Dystric Cambisol, UK	N	As (V)	6.4	7.48	21	20/16 d/n	4 d	EC50	root length	328.6	2	37,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Histosol, NL	N	As (V)	4.7	39.64	24	20/16 d/n	4 d	EC50	root length	195.4	2	32,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Histosol, UK	N	As (V)	4.2	22.00	13	20/16 d/n	4 d	EC50	root length	75.6	2	35,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Haplic Luvisol, Belgium	N	As (V)	7.4	2.14	27	20/16 d/n	4 d	EC50	root length	229.2	2	21,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Stagnic Luvisol, France	N	As (V)	7.3	2.50	38	20/16 d/n	4 d	EC50	root length	1025.8	2	24,48,4	[40]
Hordeum vulgare	seedlings (1 day)	Dystric Cambisol, UK	N	As (V)	6.4	7.48	21	20/16 d/n	4 d	EC50	root length	1165.3	2	38,48,4	[40]
Lactuca sativa	seedlings (1 day)	Paddy soil	N	As (V)	5.55	2.79	1.84	25/20 d/n	6 d	EC50	growth (root length)	426.5	3	42,48,52	[35]
Lactuca sativa	seedlings (1 day)	Red soil	N	As (V)	4.48	1.54	26.6	25/20 d/n	6 d	EC50	growth (root length)	123.7	2	40,48,52	[35]
Lactuca sativa	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.91	0.95	1.54	25/20 d/n	6 d	EC50	growth (root length)	64.8	2	41,48,52	[35]
Lactuca sativa	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.93	1	1.28	25/20 d/n	6 d	EC50	growth (root length)	59.3	2	42,48,52	[35]
Lactuca sativa	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.87	2.04	6.26	25/20 d/n	6 d	EC50	growth (root length)	104.3	2	39,48,52	[35]
Lactuca sativa	seedlings (1 day)	Black soil	N	As (V)	6.03	6.16	3.23	25/20 d/n	6 d	EC50	growth (root length)	185.5	2	43,48,52	[35]
Triticum aestivum	seedlings (1 day)	Sandy loam	N	As (V)	8.05	2.04	6.26	25/20 d/n	72 h	EC50	growth (root length)	196	2	33,47,3,52	[35]
Triticum aestivum	seedlings (1 day)	Paddy soil	N	As (V)	5.55	2.79	1.84	25/20 d/n	6 d	EC50	growth (root length)	682.9	3	42,48,52	[35]
Triticum aestivum	seedlings (1 day)	Red soil	N	As (V)	4.48	1.54	26.6	25/20 d/n	6 d	EC50	growth (root length)	268.3	2	40,48,52	[35]
Triticum aestivum	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.91	0.95	1.54	25/20 d/n	6 d	EC50	growth (root length)	181.7	2	41,48,52	[35]
Triticum aestivum	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.93	1	1.28	25/20 d/n	6 d	EC50	growth (root length)	159.1	2	42,48,52	[35]
Triticum aestivum	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.87	2.04	6.26	25/20 d/n	6 d	EC50	growth (root length)	226.2	2	39,48,52	[35]
Triticum aestivum	seedlings (1 day)	Black soil	N	As (V)	6.03	6.16	3.23	25/20 d/n	6 d	EC50	growth (root length)	337.0	2	43,48,52	[35]
Annelida															
Eisenia fetida	adult	sandy soil	N	As (III)	6	<1	5	20	14 d	LC50	survival	10.86	2	51,2,1,16	[41]
Eisenia fetida	adult	sandy soil	N	As (V)	6	<1	5	20	14 d	LC50	survival	21.73	2	51,2,1,17	[41]
Lumbricus terrestris	adult	sandy loam, 0-70mm	N	As (V)	3.6	11.5		18	10 d	LC50	survival	100	2	44,48	[42]
Lumbricus terrestris	adult	sandy loam, 0-70mm	N	As (V)	3.6	11.5		18	4 d	LC50	survival	280	2	44,48,50	[42]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Criterion	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Lumbricus terrestris	adult	loamy sand, 70-90mm	N	As (V)	3.4	2.6		18	4 d	LC50	survival	155	2	44,48,50	[42]
Lumbricus terrestris	adult	sand, 90-140mm	N	As (V)	3.6	1.5		18	4 d	LC50	survival	170	2	44,48,49	[42]
Lumbricus terrestris	adult	sand, 140-300mm	N	As (V)	3.8	1.8		18	4 d	LC50	Survival	130	2	44,48,50	[42]
Lumbricus terrestris	adult	sand, 300-500mm	N	As (V)	4.2	1.3		18	4 d	LC50	Survival	75	2	44,48,50	[42]
Lumbricus terrestris	adult	sand, 500-700mm	N	As (V)	5.1	0.8		18	4 d	LC50	Survival	70	2	44,48,49	[42]
Soil microbial community / Enzymatic activity															
Dehydrogenase activity	natural soil; 0-30cm surface	Loess soil (Ap horizon); haplic luvisol	N		7.02	1.90	15.2	21	24 hr	EC50		168	3	45,48,51	[53]
DMSO reduction	natural soil	black loam/Egmont	N	As (V)	6	20.4	32	15-21	3 d	EC50		>3745	3	53,46,51,10	[43]
DMSO reduction	natural soil	silt loam/Kaitoke	N	As (V)	5.6	13.8	25	15-21	3 d	EC50		>3745	3	55,46,51,11	[43]
DMSO reduction	natural soil	loamy sand/Foxtron	N	As (V)	5.6	7.8	3	15-21	3 d	EC50		4367	2	54,46,51,8	[43]
Phosphatase	natural soil	black loam/Egmont	N	As (V)	6	20.4	32	15-21	3 d	EC50		<749	3	53,46,51,9	[43]
Phosphatase	natural soil	silt loam/Kaitoke	N	As (V)	5.6	13.8	25	15-21	3 d	EC50		<749	3	55,46,51,14	[43]
Phosphatase	natural soil	loamy sand/Foxtron	N	As (V)	5.6	7.8	3	15-21	3 d	EC50		<749	3	54,46,51,13	[43]
Sulphatase	natural soil	black loam/Egmont	N	As (V)	6	20.4	32	15-21	3 d	EC50		2547	2	53,46,51,7	[43]
Sulphatase	natural soil	silt loam/Kaitoke	N	As (V)	5.6	13.8	25	15-21	3 d	EC50		>3745	3	55,46,51,6	[43]
Sulphatase	natural soil	loamy sand/Foxtron	N	As (V)	5.6	7.8	3	15-21	3 d	EC50		712	2	54,46,51,12	[43]
Urease activity	surface soil	silt loam	N	As (III)	5.1	2.6	17	37	2 h	EC50		<37.5	2	56	[30]
Urease activity	surface soil	clay loam	N	As (III)	6.1	5.6	30	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	loam	N	As (III)	5.8	4.4	23	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	clay loam	N	As (III)	7.8	6.4	30	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	silty clay	N	As (III)	6.8	7.4	42	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	silty clay loam	N	As (III)	7.4	9.3	34	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	silt loam	N	As (V)	5.1	2.6	17	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	clay loam	N	As (V)	6.1	5.6	30	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	loam	N	As (V)	5.8	4.4	23	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	clay loam	N	As (V)	7.8	6.4	30	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	silty clay	N	As (V)	6.8	7.4	42	37	2 h	EC50		>37.5	2	56	[30]
Urease activity	surface soil	silty clay loam	N	As (V)	7.4	9.3	34	37	2 h	EC50		>37.5	2	56	[30]

Notes

1 As (III) more toxic than As (V)
2 As in control soil not specified
3 authors states "Silt loam" sandy loam is considered more appropriate
4 based on ISO 11269-1
5 dehydrogenase assay was performed in tubes, mixed on a vortex mixer (1g dry soil and 0.75ml solution): too wet for a terrestrial assay
6 EC50 = 160 μmol/g; EC50 > highest test conc.
7 EC50 = 297 μmol/g; EC50 > highest test conc.
8 EC50 = 3.29 μmol/g; EC50 < lowest test conc. and around As in control soil
9 EC50 = 34 μmol/g
10 EC50 = 5.43 μmol/g; EC50 < lowest test conc. and even lower than As in control soil
11 EC50 = 5.08 μmol/g; EC50 < lowest test conc.
12 EC50 = 58.3 μmol/g
13 EC50 = 9.5 μmol/g
14 EC50 = 95.2 μmol/g; EC50 > highest test conc.
15 endpoint determined from figure in publication
16 LC50 = 0.145 μmol/g
17 LC50 = 0.290 μmol/g
18 natural soil from Belgium with background concentration lower than the detection limit; Organic C = 9.8 g/kg
19 natural soil from France with background concentration lower than the detection limit; Organic C = 7.6 g/kg
20 natural soil from France with background concentration of 1.8 mg As/kg; Organic C = 12.6 g/kg
21 natural soil from France with background concentration of 1.8 mg As/kg; Organic C = 12.6 g/kg; soil has been aged during 3 months

22 natural soil from France with background concentration of 134.8 mg As/kg; Organic C = 15.1 g/kg
23 natural soil from France with background concentration of 151.8 mg As/kg; Organic C = 14.7 g/kg
24 natural soil from France with background concentration of 151.8 mg As/kg; Organic C = 14.7 g/kg; soil has been aged during 3 months
25 natural soil from Greece with background concentration of 5.8 mg As/kg; Organic C = 26.1 g/kg
26 natural soil from Greece with background concentration of 7.5 mg As/kg; Organic C = 4.1 g/kg
27 natural soil from Italy with background concentration lower than the detection limit; Organic C = 8.7 g/kg
28 natural soil from Spain with background concentration lower than the detection limit; Organic C = 3.8 g/kg
29 natural soil from Spain with background concentration of 3.5 mg As/kg; Organic C = 5.3 g/kg
30 natural soil from Sweden with background concentration lower than the detection limit; Organic C =16.3 g/kg
31 natural soil from The Netherlands with background concentration of 1.8 mg As/kg; Organic C =12.7 g/kg
32 natural soil from The Netherlands with background concentration of 2.6 mg As/kg; Organic C = 233.2 g/kg
33 natural soil from the suburb of Beijing with 12.2 mg As/kg
34 natural soil from UK with background concentration lower than the detection limit; Organic C = 129.4 g/kg
35 natural soil from UK with background concentration lower than the detection limit; Organic C = 129.4 g/kg; soil has been aged during 3 months
36 natural soil from UK with background concentration of 3.4 mg As/kg; Organic C = 52.0 g/kg
37 natural soil from UK with background concentration of 39.2 mg As/kg; Organic C = 44.0 g/kg
38 natural soil from UK with background concentration of 39.2 mg As/kg; Organic C = 44.0 g/kg; soil has been aged during 3 months
39 natural soils from China with 12.2 mg As/kg
40 natural soils from China with 38.6 mg As/kg
41 natural soils from China with 7.79 mg As/kg
42 natural soils from China with 8.73 mg As/kg
43 natural soils from China with 9.95 mg As/kg
44 natural soils from UK with 1.2 mg As/kg
45 organic C = 1.12 %; Sand 9.7%; Silt 75.1 %; As conc. in control soil = 9.15 mg/kg
46 other parameters studied but no effect or increase in enzyme activity
47 pH determined in H_2O
48 pH determined in $CaCl_2$
49 range of 2 LC50-values estimated from figure
50 range of 3 LC50-values estimated from figure
51 Test results based on nominal conc.
52 Test parameter does not include As conc. in control
53 Tot C=12%; Ac conc. in control soil = 9.9 µmol/g
54 Tot C=4.6%; Ac conc. in control soil = 2.7 µmol/g
55 Tot C=8.1%; Ac conc. in control soil = 1.2 µmol/g
56 only one concentration tested, 0.5 µmol/g soil

Table A2.2 Chronic toxicity of arsenic to soil organisms

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Insecta															
Folsomia candida	juveniles (10-12 d)	OECD artificial (conform ISO)	N	As (V)	5	10	20	20	15 d	NOEC	growth	2.22	2	94	[44]
Folsomia candida	juveniles (10-12 d)	OECD artificial (conform ISO)	N	As (V)	5	10	20	20	35 d	NOEC	reproduction	0.74	2	92,39	[44]
Folsomia candida	adults (10-12 d)	artificial (OECD 207)	Y	As (V)	6	10	20	20	28 d	NOEC	reproduction	<10	2	91,84,44	[47]
Annelida															
Dendrodrilus rubidus	large juveniles/adult	soil from a mixed deciduous woodland	N	As (V)	4.7	9.9		9	28 d	NOEC	condition index	<494	2	83,74	[45]
Eisenia fetida	adults	artificial soil (OECD 207)	Y	As (V)	6	10	20	20	21 d	NOEC	reproduction (cocoon production)	10	2	84,44	[47]
Eisenia fetida	adult	sandy soil	N	As (V)	6	<1	5	20	28 d	NOEC	survival	3.75	2	64,16	[46]
Eisenia fetida	adult	sandy soil	N	As (V)	6	<1	5	20	28 d	NOEC	growth (body weight)	1.87	2	63,16	[46]
Eisenia fetida	adult	sandy soil	N	As (V)	6	<1	5	20	28 d	NOEC	reproduction (cocoon production)	>7.49	3	65,86,16	[46]
Eisenia fetida	adult	sandy soil	N	As (V)	6	<1	5	20	28 d	NOEC	lysosomal membrane integrity (Neutral Red Retention Time)	1.87	2	63,16	[46]
Eisenia fetida	adult	sandy soil	N	As (III)	6	<1	5	20	28 d	NOEC	growth (body weight)	1.87	2	63,7,16	[41]
Eisenia fetida	adult	sandy soil	N	As (III)	6	<1	5	20	28 d	EC10	reproduction (cocoon production)	1.42	3	24,7,40,16	[41]
Enchytraeus albidus	adults	artificial soil (OECD 207)	Y	As (V)	6	10	20	20	42 d	NOEC	reproduction	10	2	84,44,93,5	[47]
Lumbricus rubellus	adult	clay loam	Y	As (V)	7.1	±5	41	14	28 d	NOEC	mortality	>125	2	22,32,44,43,97	[34]
Lumbricus rubellus	adult	clay loam	Y	As (V)	7.1	±5	41	14	28 d	NOEC	reproduction (cocoon production)	36	2	22,32,44,43,97	[34]
Lumbricus rubellus	juveniles	clay loam	Y	As (V)	7.1	±5	41	14	280 d	NOEC	growth (biomass)	12	2	22,44,43,97	[34]
Lumbricus rubellus	juveniles	clay loam	Y	As (V)	7.1	±5	41	14	140 d	NOEC	growth (biomass)	36	2	22,44,43,97	[34]
Lumbricus rubellus	juveniles/adult	clay loam	Y	As (V)	7.1	±5	41	14	280 d	NOEC	population growth rates	12	2	22,96,44,43,97	[34]
Lumbricus rubellus	large juveniles/adult	soil from a mixed deciduous woodland	N	As (V)	5.0	9.9		9	28 d	NOEC	condition index	<2000	2	73,74	[54]
Lumbricus rubellus	large juveniles/adult	soil from a mixed deciduous woodland	N	As (V)	4.7	9.9		9	28 d	NOEC	condition index	<494	2	83,74	[45]
Macrophyta															
Acacia mangium	seeds	oxisol+sand	N	As (III)	6.2	4.3	55		120 d	EC10	growth (root weight)	14.3	2	89,83,14	[51]
Acacia mangium	seeds	oxisol+sand	N	As (III)	6.24	4.27	55		120 d	EC10	growth (shoot weight)	18.6	2	89,83,14	[51]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Brassica juncea	plants, 30d old	garden soil	N	As (V)				15-25	30 d	NOEC	seed weight	10	4	88,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (III)				15-25	30 d	NOEC	seed weight	>50	4	88,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (V)				15-25	15 d	NOEC	root length	>50	4	87,60,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (III)				15-25	15 d	NOEC	root length	>50	4	87,60,90,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (V)				15-25	15 d	NOEC	shoot length	<10	4	87,61,90,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (III)				15-25	15 d	NOEC	shoot length	<10	4	87,61,90,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (V)				15-25	15 d	NOEC	fresh weight	<10	4	87,61,90,104	[55]
Brassica juncea	plants, 30d old	garden soil	N	As (III)				15-25	15 d	NOEC	fresh weight	<10	4	87,61,90,104	[55]
Brassica napus	seedlings (14d)	silt loam commerce	N	As (V)	5.2	0.30	13	20/15 d/n	14 d	NOEC	dry weight (both shoot and root)	>10	3*	11,83,79,28,105	[56]
Brassica napus	seedlings (14d)	silt loam Rilla	N	As (V)	5.6	0.28	5	20/15 d/n	14 d	NOEC	dry weight (both shoot and root)	>10	3*	12,83,78,28,34, 105	[56]
Brassica napus	seedlings (14d)	silt loam Sterlington	N	As (V)	6.4	0.15	4	20/15 d/n	14 d	NOEC	dry weight (both shoot and root)	>10	3*	13,83,79,28,105	[56]
Brassica napus	seedlings (14d)	silt loam commerce	N	As (V)	5.2	0.30	13	20	14 d	NOEC	dry weight (both shoot and root)	>10	3	11,83,80,105	[57]
Brassica napus	seedlings (14d)	silt loam Rilla	N	As (V)	5.6	0.28	5	20	14 d	NOEC	dry weight (both shoot and root)	>10	3	12,83,80,35,105	[57]
Brassica napus	seedlings (14d)	silt loam Sterlington	N	As (V)	6.4	0.15	4	20	14 d	NOEC	dry weight (both shoot and root)	>10	3	13,83,80,105	[57]
Cicer arietinum	seeds	garden soil	N	As (V)				open field conditions	harvested after mature fruiting stage	NOEC	shoot length	<10	4	76,90,104	[58]
Cicer arietinum	seeds	garden soil	N	As (V)				open field conditions	harvested after mature fruiting stage	NOEC	root length	<10	4	76,90,104	[58]
Cicer arietinum	seeds	garden soil	N	As (V)				open field conditions	harvested after mature fruiting stage	NOEC	fresh weight	<10	4	76,90,104	[58]
Cicer arietinum	seeds	garden soil	N	As (V)				open field conditions	harvested after mature fruiting stage	NOEC	plant biomass	<10	4	76,90,104	[58]
Echinochloa crusgalli	seeds	loamy sand	Y	As (V)	4.2	1.23	10.1	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	54	3	59,44,100,82,23	[59]
Echinochloa crusgalli	seeds	sandy loam	Y	As (V)	3.7	0.69	6.82	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	31	3	57,44,100,82,23	[59]
Echinochloa crusgalli	seeds	loam	Y	As (V)	5.5	2.43	22.2	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	<160	3	55,44,100,82,23	[59]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Echinochloa crusgalli	seeds	clay loam	Y	As (V)	7.3	1.12	28.6	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	49	3	58,44,100,82,23	[59]
Echinochloa crusgalli	seeds	clay	Y	As (V)	5.6	4.06	41.8	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	<245	3	56,44,100,82,23	[59]
Eucalyptus globulus	seedlings (21d)	Andisol Acrudoxic Hapludands	N	As (V)	5.4			20/19 d/n	12 weeks	NOEC	dry weight (both shoot and root)	<25	3	99	[60]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	8.2	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	4.6	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	40.4	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	13.3	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	32.0	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	4.5	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	2.6	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	14.6	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	10.9	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	10.4	2	95,41	[48]
Lactuca sativa	seeds	artificial soil	N	As (V)			20	24	21 d	EC10	root elongation	8.7	2	95,41	[48]
Lactuca sativa	seedlings (1 day)	Paddy soil	N	As (V)	5.6	2.79	1.84	25/20 d/n	6 d	NOEC	growth (root length)	200	3	82,97,53	[35]
Lactuca sativa	seedlings (1 day)	Red soil	N	As (V)	4.5	1.54	26.6	25/20 d/n	6 d	NOEC	growth (root length)	40	2	82,97,51,106	[35]
Lactuca sativa	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.9	0.95	1.54	25/20 d/n	6 d	NOEC	growth (root length)	<40	2	82,97,52,106	[35]
Lactuca sativa	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.9	1	1.28	25/20 d/n	6 d	NOEC	growth (root length)	<40	2	82,97,53,106	[35]
Lactuca sativa	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.9	2.04	6.26	25/20 d/n	6 d	NOEC	growth (root length)	60	2	82,97,50,106	[35]
Lactuca sativa	seedlings (1 day)	Black soil	N	As (V)	6.0	6.16	3.23	25/20 d/n	6 d	NOEC	growth (root length)	90	2	82,97,54,106	[35]
Lolium perenne	seeds	loamy sand	Y	As (V)	4.2	1.23	10.1	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	<39	3	59,44,100,82,23	[59]
Lolium perenne	seeds	sandy loam	Y	As (V)	3.67	0.69	6.82	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	12	3	57,44,100,82,23	[59]
Lolium perenne	seeds	loam	Y	As (V)	5.53	2.43	22.2	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	31	3	55,44,100,82,23	[59]
Lolium perenne	seeds	clay loam	Y	As (V)	7.34	1.12	28.6	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	27	3	58,44,100,82,23	[59]
Lolium perenne	seeds	clay	Y	As (V)	5.57	4.06	41.8	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	79	3	56,44,100,82,23	[59]
Ludwigia octovalvis	plants, 8 weeks old	sand	N	As (V)	5.5-7.0			25.5-27.8	28 d	NOEC	cumulative effect (wilting, dried and death)	40	3	46	[61]
Ludwigia octovalvis	plants, 8 weeks old	sand	Y	As (V)	7.3-9.2			24.2-28.5	21 d	NOEC	growth (wet and dry weight)	<5	3	2,1,45	[62]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Lycopersicon esculentum	young plants (primary leaf stage)	alluvial delluvial soil	N	As (III)	6.6	3.8		18-22	20 d	NOEC	growth (stem weight)	50	2	48,83,29,37	[39]
Lycopersicon esculentum	young plants (primary leaf stage)	alluvial delluvial soil	N	As (III)	6.6	3.8		18-22	20 d	NOEC	growth (root weight)	25	2	48,83,29,36	[39]
Lycopersicon esculentum	young plants (primary leaf stage)	alluvial delluvial soil	N	As (III)	6.6	3.8		18-22	20 d	NOEC	growth (leaf weight)	15	2	48,83,29	[39]
Lycopersicon esculentum	seedlings	alluvial-delluvial meadow soil	N	As (III)	6.6	4.2		18-22	60 d	NOEC	growth (root length)	<25	2	10	[63]
Lycopersicon esculentum	seedlings	alluvial-delluvial meadow soil	N	As (III)	6.6	4.2		18-22	60 d	NOEC	growth (root dry weight)	<25	2	10	[63]
Lycopersicon esculentum	seedlings	alluvial-delluvial meadow soil	N	As (III)	6.6	4.2		18-22	60 d	NOEC	growth (shoot length)	50	2	10	[63]
Lycopersicon esculentum	seedlings	alluvial-delluvial meadow soil	N	As (III)	6.6	4.2		18-22	60 d	NOEC	growth (shoot dry weight)	25	2	10	[63]
Medicago sativa	seeds	loamy sand	Y	As (V)	4.2	1.23	10.1	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	29	3	59,44,100,82,23	[59]
Medicago sativa	seeds	loam	Y	As (V)	5.53	2.43	22.2	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	12	3	55,44,100,82,23	[59]
Medicago sativa	seeds	clay loam	Y	As (V)	7.34	1.12	28.6	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	30	3	58,44,100,82,23	[59]
Medicago sativa	seeds	clay	Y	As (V)	5.57	4.06	41.8	20/18.5 d/n	40 d	EC10	growth (dry matter above ground)	84	3	56,44,100,82,23	[59]
Mimosa caesalpiniaefolia	seedlings	oxisol+sand	N	As (III)	6.24	4.27	55		120 d	EC10	growth (root weight)	12.6	3	89,83,14,61	[51]
Mimosa caesalpiniaefolia	seedlings	oxisol+sand	N	As (III)	6.24	4.27	55		120 d	EC10	growth (shoot weight)	32.2	2	89,83,14	[51]
Oryza sativa	seedlings (15d)	Inceptisol; sand 41,7%	Y	As (V)	7.54	0.71	<45%		30 d	NOEC	development (nr of seedlings)	15	3	102,98	[64]
Oryza sativa	seedlings (15d)	Inceptisol; sand 41,7%	Y	As (V)	7.54	0.71	<45%		30 d	NOEC	development (nr of tillers)	20	3	102,98	[64]
Oryza sativa	seedlings (15d)	Inceptisol; sand 41,7%	Y	As (V)	7.54	0.71	<45%		30 d	NOEC	reproduction (nr mature grains/panicle)	10	3	102,98	[64]
Oryza sativa	seedlings (15d)	Inceptisol; sand 41,7%	Y	As (V)	7.54	0.71	<45%		30 d	NOEC	reproduction (grain yield)	10	3	102,98	[64]
Oryza sativa	seedlings (15d)	Inceptisol; sand 41,7%	Y	As (V)	7.54	0.71	<45%		30 d	NOEC	chlorophyll-a and -b	20	3	102,98	[64]
Oryza sativa	seedlings	Clay (Pinchen)	Y	As (V)	4.3	1.9		25/20 d/n	38 d	NOEC	growth (shoot dw)	<200	3	17,75	[65]
Oryza sativa	seedlings	Sandy loam (Tainan)	Y	As (V)	5.0	1.7		25/20 d/n	38 d	NOEC	growth (shoot dw)	<200	3	19,75	[65]
Oryza sativa	seedlings	Clay Loam (Neipu)	Y	As (V)	4.3	1.4		25/20 d/n	38 d	NOEC	growth (shoot dw)	<200	3	20,75	[65]
Oryza sativa	seedlings	Clay loam (Chiwulan)	Y	As (V)	4.9	4.5		25/20 d/n	38 d	NOEC	growth (shoot dw)	<200	3	18,75	[65]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Pisum sativum	seeds	artificial soil	N	As (V)	5.6			18-30	12 d	NOEC	growth (shoot dw)	5	2	8	[36]
Pisum sativum	seeds	artificial soil	N	As (V)	5.6			18-30	12 d	NOEC	growth (shoot dw)	<3	2	8	[36]
Pisum sativum	seeds	artificial soil	N	As (V)	5.6			18-30	12 d	NOEC	growth (shoot dw)	<3	3	8,42	[36]
Pisum sativum	seeds	artificial soil	N	As (V)	5.6			18-30	32 d	NOEC	growth (shoot dw)	<1.8	2	8	[36]
Pisum sativum	seeds	artificial soil	N	As (V)	5.6			18-30	32 d	NOEC	growth (shoot dw)	5.3	2	8	[36]
Pteris vittata	seedlings	natural soil	N	As (V)	7.9			25-30 day; 15-20 night	24 weeks	NOEC	frond biomass	<100	2	47,83,9	[37]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	EC10	germination	8.4	3	62	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	EC10	germination	<3	3	66,27	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	germination	7	3	66,26	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	germination	10	3	62	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	shoot length	3	3	66	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	shoot length	10	3	62,6	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	root elongation	15	3	66	[66]
Solanum nigrum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	root elongation	10	3	62,21	[66]
Solanum tuberosum	pre-sprouted tubers	loamy - clay-loamy	N			2.28		variable; field test	139 d	NOEC	growth (leaf area)	30	2	31,15	[49]
Solanum tuberosum	pre-sprouted tubers	loamy - clay-loamy	N			2.28		variable; field test	139 d	NOEC	=growth (tuber yield)	60	2	31,15,81	[49]
Trifolium incarnatum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	EC10	inhibition of germ.	4.4	3	62,33,38	[66]
Trifolium incarnatum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	EC10	inhibition of germ.	<3	3	66,33,25	[66]
Trifolium incarnatum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	inhibition of germ.	<3	3	66,33	[66]
Trifolium incarnatum	seeds	sand (Areipor)	N	As (V)	7			rt (± 23°C)	4 weeks	NOEC	inhibition of germ.	3	3	66,33	[66]
Triticum aestivum	seedlings (14d); variety Jimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (root biomass)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Gaoyou	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (root biomass)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Weimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (root biomass)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Wennong	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (root biomass)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Jimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (stems biomass)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Gaoyou	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (stems biomass)	50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Weimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (stems biomass)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Wennong	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (stems biomass)	50	2	30,100,69,83	[38]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Triticum aestivum	seedlings (14d); variety Jimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (spikes biomass)	50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Gaoyou	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (spikes biomass)	50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Weimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (spikes biomass)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Wennong	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	growth (spikes biomass)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Jimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikes per plant)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Gaoyou	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikes per plant)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Weimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikes per plant)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Wennong	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikes per plant)	<50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Jimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikelets per spike)	50	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Gaoyou	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikelets per spike)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Weimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikelets per spike)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Wennong	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (spikelets per spike)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Jimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (grains per year)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Gaoyou	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (grains per year)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Weimai	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (grains per year)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (14d); variety Wennong	coarse-silty loam	N	As (V)	7.8	1.16	7.82	outside under rain shelter	mature plants harvested	NOEC	yield (grains per year)	>100	2	30,100,69,83	[38]
Triticum aestivum	seedlings (1 day)	Paddy soil	N	As (V)	5.6	2.79	1.84	25/20 d/n	6 d	NOEC	growth (root length)	200	3	82,97,53	[35]
Triticum aestivum	seedlings (1 day)	Red soil	N	As (V)	4.5	1.54	26.6	25/20 d/n	6 d	NOEC	growth (root length)	135	2	82,97,51,106	[35]
Triticum aestivum	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.9	0.95	1.54	25/20 d/n	6 d	NOEC	growth (root length)	90	2	82,97,52,106	[35]
Triticum aestivum	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.9	1	1.28	25/20 d/n	6 d	NOEC	growth (root length)	60	2	82,97,53,106	[35]
Triticum aestivum	seedlings (1 day)	Fluvoaquic soil	N	As (V)	7.9	2.04	6.26	25/20 d/n	6 d	NOEC	growth (root length)	60	2	82,97,50,106	[35]
Triticum aestivum	seedlings (1 day)	Black soil	N	As (V)	6.0	6.16	3.23	25/20 d/n	6 d	NOEC	growth (root length)	135	2	82,97,54,106	[35]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Soil microbial community / Enzymatic activity															
Active microbial biomass carbon	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	NOEC		<0.1	2	77,72	[50]
Active microbial biomass carbon	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	EC10		0.17	2	77,72,107	[50]
Active microbial biomass carbon	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	NOEC		0.1	2	71	[50]
Active microbial biomass carbon	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	EC10		0.0033	2	71,107	[50]
Active microbial biomass carbon	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	NOEC		0.1	2	67	[50]
Active microbial biomass carbon	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	EC10		0.13	2	67,107	[50]
Basal soil respiration	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	NOEC		<0.1	2	72	[50]
Basal soil respiration	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	EC10		0.28	2	72,107	[50]
Basal soil respiration	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	NOEC		<0.1	2	71	[50]
Basal soil respiration	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	EC10		0.0068	2	71,107	[50]
Basal soil respiration	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	NOEC		<0.1	2	77,67	[50]
Basal soil respiration	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	EC10		6.4	2	77,67,107	[50]
Dehydrogenase activity	rhizosphere flora from Jatropha multifida	T1, garden soil from under a lawn	Y	As (V)	7.6-8.7	0.7			1 year	NOEC		25	3	85,68,4,3	[67]
Dehydrogenase activity	rhizosphere flora from Jatropha multifida	T2, garden soil from under a lawn mixed with biosludge from a waste water treatment	Y	As (V)	7.6-8.7	2.14			1 year	NOEC		25	3	85,70,4,3	[67]
Dehydrogenase activity	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	NOEC		0.1	2	77,72	[50]
Dehydrogenase activity	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	EC10		0.96	2	77,72,107	[50]
Dehydrogenase activity	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	NOEC		1	2	71	[50]
Dehydrogenase activity	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	EC10		6.8	2	71,107	[50]
Dehydrogenase activity	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	NOEC		1	2	67	[50]
Dehydrogenase activity	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	EC10		0.92	2	67,107	[50]
FDA-hydrolase	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	NOEC		0.1	2	77,72	[50]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
FDA-hydrolase	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	EC10		0.75	2	77,72,107	[50]
FDA-hydrolase	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	NOEC		1	2	71	[50]
FDA-hydrolase	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	EC10		0.40	2	71,107	[50]
FDA-hydrolase	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	NOEC		<0.1	2	67	[50]
FDA-hydrolase	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	EC10		0.0059	2	67,107	[50]
Microbial biomass	rhizosphere flora from Jatropha multifida	T1, garden soil from under a lawn	Y	As (V)	7.6-8.7	0.7			1 year	NOEC		<25	3	85,68,4,3	[67]
Microbial biomass	rhizosphere flora from Jatropha multifida	T2, garden soil from under a lawn mixed with biosludge from a waste water treatment	Y	As (V)	7.6-8.7	2.14			1 year	NOEC		25	3	85,70,4,3	[67]
Microbial biomass carbon	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	NOEC		<0.1	2	77,72	[50]
Microbial biomass carbon	nat. soil; 0-10cm	Vertisol; black soil	N	As (V)	8.4	3.74	40	28	10 d	EC10		116	2	77,72,107	[50]
Microbial biomass carbon	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	NOEC		<0.1	2	71	[50]
Microbial biomass carbon	nat. soil; 0-10cm	Inceptisol; alluvial soil	N	As (V)	7.4	2.98	25	28	10 d	EC10		0.017	2	71,107	[50]
Microbial biomass carbon	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	NOEC		1	2	67	[50]
Microbial biomass carbon	nat. soil; 0-10cm	Entisol; red soil	N	As (V)	4.8	0.11	10	28	10 d	EC10		5.6	2	67,107	[50]
Nitrogen mineralisation	natural soil; 0-15 cm surface	loam	N	As (III)	5.8	4.386	23	30	20 d	NOEC		<1.125	2	103	[29]
Nitrogen mineralisation	natural soil; 0-15 cm surface	silty clay	N	As (III)	6.6	5.0	45	30	20 d	NOEC		<1.125	2	103	[29]
Nitrogen mineralisation	natural soil; 0-15 cm surface	clay loam	N	As (III)	7.8	6.4	30	30	20 d	NOEC		<1.125	2	103	[29]
Nitrogen mineralisation	natural soil; 0-15 cm surface	silty clay loam	N	As (III)	7.4	9.3	34	30	20 d	NOEC		<1.125	2	103	[29]
Nitrogen mineralisation	natural soil; 0-15 cm surface	loam	N	As (V)	5.8	4.386	23	30	20 d	NOEC		<1.125	2	103	[29]
Nitrogen mineralisation	natural soil; 0-15 cm surface	silty clay	N	As (V)	6.6	5.0	45	30	20 d	NOEC		<1.125	2	103	[29]
Nitrogen mineralisation	natural soil; 0-15 cm surface	clay loam	N	As (V)	7.8	6.4	30	30	20 d	NOEC		<1.125	2	103	[29]

Species	Species properties	Soil type	A	Test comp.	pH	OM [%]	clay [%]	Temp [°C]	Exp. time	Crit.	Endpoint	Result [mg/kg$_{dwt}$]	Ri	Notes	Ref.
Nitrogen mineralisation	natural soil; 0-15 cm surface	silty clay loam	N	As (V)	7.4	9.3	34	30	20 d	NOEC		<1.125	2	103	[29]
Phosphatase	phosphatase from soil sample	brown soil	N	As (III)	6.5			28	10 d	EC50		18.1	3	49,104	[68]

Notes

1 according ISO 11269-2
2 according OECD 208
3 actual As conc. in soil 64% of nominal; test results based on nominal conc.
4 additional experiment performed in which a biofertilizer was added, data not included
5 adults removed after 21 days
6 all concentrations have higher shoot length compared to control; At 15 mg/kg no germination
7 article also specifies tox data for As (V) but these are similar to those reported in Lee and Kim (2009) except for the fact that the NOEC value has changed from 0.025 to 0.1; original NOEC from 2009 seems more realistic; Their conclusion that "As (III) is more toxic than As (V) based on all parameters", seems only valid for mortality
8 article focuses on As-effects on nutrient balances for which growth was measured as reference; As-conc. in control soil = 0.56 mg/kg
9 article focuses on the effects of As on chloroplast ultrastructure and calcium distribution. Test concentrations were therefore too high to measure NOEC for growth accurately.
10 As conc. in control soil = 1.8 mg/kg; study also includes effects on chla+b and peroxidase, data not included in this overview
11 As conc. in control soil: 4.2 mg As/kg;
12 As conc. in control soil: 5.2 mg As/kg;
13 As conc. in control soil: 9.8 mg As/kg;
14 As conc. measured in extract, dose in soil not verified; EC10 determined from figure
15 As concentration in control soil unknown
16 As in control not specified
17 As-conc. in control soil=12 mg/kg
18 As-conc. in control soil=19 mg/kg
19 As-conc. in control soil=7.6 mg/kg
20 As-conc. in control soil=9.1 mg/kg
21 at 15 mg/kg no germination; At 10 mg/kg root length is reduced by 50% but not significant due to high variation
22 commercially available soil with 16.5 mg As/kg, amended with 3% composted bark
23 EC10 determined from EC20 and EC50
24 EC10=0.019 µmol/g
25 estimated EC10 = 0.4 mg As/kg
26 estimated EC10 = 1.6 mg As/kg
27 estimated EC10 = 1.6 mg As/kg; NOEC higher, probably high variation in replica's
28 experiment looks strongly like Cox et al 1996, but data are slightly different
29 experiment performed twice a year and during two consecutive years; dose-response is not very steep
30 field experiment; natural soil with 1.84 mg As/kg; Silt: 52%; Sand: 19%
31 field tests in 3 consecutive years and with two varieties; NOEC is based on statistical analyses of all 3 years; In first year effects are stronger and a significant interaction factor As*year exists.
32 food spiked with As
33 germination in control is only 40%
34 growth in Rilla soil, control included, was low, indicating other stressors

35 growth in Rilla soil, control included, was very low, possibility that residual amounts of herbicide may have caused the growth problems
36 hormesis observed in 15 and 25 mg/kg
37 hormesis observed in 15, 25 and 50 mg/kg
38 hormesis observed in the lowest conc.
39 hormesis observed: smaller reproduction in control than in 4 lowest test concentrations
40 in comparison with Lee and Kim (2009) also for their work from 2013 it should be concluded that reproduction was low and variable, also for control treatment
41 interaction between Fe and org matter on As toxicity is studied in 11 artificial soils; for OM the level of mushroom compost is taken over; EC10 values determined from data in figures
42 interrupted dose response relation
43 level of OM and clay reported in Spurgeon et al 2004
44 measured concentrations were >80% of nominal, test result based on nominal concentrations
45 measurements during the test were made on 1 plant per replicate, while 3 plants were used after 91 days; natural sand with As < detection limit; prolonged phytotoxicity test up to 91 days, but decreasing plant biomass in control after 21 days, possibly due to decreasing nutrient since no additional nutrient was added; Bioavailable As significantly decreased during the experiment in all conc., reductions ranged between 64-100%; Total As conc. are measured according to Math&Meth but not reported; Parent plant originated from contaminated site; pH range during test is rather large; statistics for NOEC unclear (ANOVA are mentioned but not post-hoc tests); As dry weight in control decreased after 21days, growth during the first 3 weeks might also be limited by nutrient shortage
46 natural sand with As < detection limit; range finding test; test results based on nominal concentrations; NOEC estimated, no statistical analyses; As measurements in soil aimed only at available conc., not at the total conc.; predicted EC50 between 40 and 60 mg/kg; plants were wilting after 3 days of exposure in 40 mg/kg, but became healthy after 7 days. Several leaves in control fell after 21 days, could be due to decreasing nutrient since no additional nutrient was added. Dropping leaves in 40 mg/kg started after 7 days. Decreasing bioavailable As concentrations after 7 days, reduction between 13 and 70 %. pH increased with increasing As-conc.; parent plant originated from contaminated site
47 natural soil from Being with As conc. in control soil: 9 mg As/kg
48 natural soil with As conc. in control soil: 1.05 mg As/kg
49 natural soil; table with soil characteristics is missing in the article; Experiment lasted 60 d; strongest effects occurred after 10d exposure; thereafter acclimation/adaptation occurred. Insufficient data to estimate NOEC ourselves
50 natural soils from China with 12.2 mg As/kg
51 natural soils from China with 38.6 mg As/kg
52 natural soils from China with 7.79 mg As/kg
53 natural soils from China with 8.73 mg As/kg
54 natural soils from China with 9.95 mg As/kg
55 natural soils from USA; OC=14.3 g/kg
56 natural soils from USA; OC=23.9 g/kg
57 natural soils from USA; OC=4.06 g/kg
58 natural soils from USA; OC=6.57 g/kg
59 natural soils from USA; OC=7.21 g/kg
60 no effect in highest conc. of 50 mg/kg
61 no increase of effect at higher As conc.
62 no nutrition; test procedure seems to use clean sand only due to which the test might just as well be considered as a water-only exposure
63 NOEC=0.025 µmol/g
64 NOEC=0.05 µmol/g
65 NOEC>0.1 µmol/g

66 nutritive solution used; test procedure seems to use clean sand only due to which the test might just as well be considered as a water-only exposure
67 OC=0.064%
68 OC=0.41 %
69 OC=0.685%, recalculated as OM = 1.16, while OM is also specified in article as 1.45%
70 OC=1.26 %
71 OC=1.75%
72 OC=2.2%
73 OM content of this soil reported in Landon et al 2001
74 only 1 conc. tested
75 only one conc. tested (200 mg/kg), test probably not performed under aerobic conditions
76 only one concentration tested; Conc. of 10 mg/kg was chosen knowing that it will cause an effect as the study aimed at a reduction of the effect by adding a bacterial strain to the soil.
77 only small % of effect at LOEC
78 only two As conc. tested (5 and 10 mg/kg); visual toxicity symptoms (chlorosis, wilting and stunted growth) were apparent in the shoot tissue
79 only two As conc. tested (5 and 10 mg/kg); visual toxicity symptoms (chlorosis, wilting and stunted growth) were apparent in the shoot tissue and shoot P uptake decreased
80 only two As conc. tested (5 and 10 mg/kg); visual toxicity symptoms (chlorosis, wilting and stunted growth) were apparent in the shoot tissue but it is not specified at which conc.
81 percentage reduction in yield at NOEC in first year is on average 38%
82 pH determined in $CaCl_2$
83 pH determined in H_2O
84 pH determined in KCl
85 pH value decreased with increasing As, range is specified; 2 As conc. tested; NOEC estimated from figures, no statistics or stdev. specified; due to long exposure acclimation of microbial populations might have occurred
86 reproduction was low and variable, also for control (probably caused by low amount of OM) and therefore no statistical significant effects
87 soil analyses only considered EDTA-available As, not the total conc.
88 soil analyses only considered EDTA-available As, not the total conc.; study also includes effects on chla+b and several enzymes, data not included in this overview
89 soil consists of three quarter of an Oxisol to one quarter of coarse sand
90 study also includes effects on chla+b and several enzymes, data not included in this overview
91 test according to ISO (1999)
92 test according to ISO 11267, 1998
93 test according to OECD 220
94 test based on ISO 11267, 1998
95 test based on OECD 208
96 test duration based on juvenile growth, although population growth model also incorporates parameters from adult exposure (28d)
97 test parameter does not include As conc. in control
98 test result based on nominal concentrations, measured concentrations were <50% of nominal at end of experiment
99 test result based on visual inspection of data from figure; Dose-response unclear. No increase of effect at higher concentrations
100 test soils mixed with vermiculite (50% volume), As concentrations based on soil only actual exposure concentration unknown, furthermore, since vermiculite is known to have a high CEC, the availability of the test compound is considered to be highly affected. The endpoint is considered unreliable
101 two arsenic treatments: 50 and 100 mg/kg tested
102 uncontaminated soil from West Bengal, India with an As conc. in control soil of 3.33 mg As/kg; As added 15 days after sowing; OC=4.18 g/kg
103 only one concentration tested, 3 ml of 50 μM solution added to 10 gram soil; at this level only small effect were observed
104 composition of the soil unclear
105 level of organic matter too low
106 origin of soil unknown but soil parameters indicate that the soil can be considered relevant for our report
107 EC10 determined from figure

RIVM
Committed to *health and sustainability*