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Sustainable Compost Application in Agriculture

Completion April 2008

- English Version of the Summary of the German Report-

Baden-Württemberg
LANDWIRTSCHAFTLICHES TECHNOLOGIE-ZENTRUM AUGUSTENBERG (LTZ)

CENTER FOR AGRICULTURAL TECHNOLOGY AUGUSTENBERG (LTZ)

Sustainable Compost Application in Agriculture

Completion April 2008 - English Version of the Report Summary

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ltz	**Center for Agricultural Technology Augustenberg (LTZ)** of the Ministry for Food and Rural Areas (Ministerium für Ernährung und Ländlicher Raum Baden-Württemberg) Germany Director: Dr. Norbert Haber

In cooperation with

HELMHOLTZ ZENTRUM FÜR UMWELTFORSCHUNG UFZ	Helmholtz Centre for Environmental Research - UFZ, Department of Soil Ecology, Halle Scientific Director: Prof. Georg Teutsch
Bioplan Dr. Reinhold und Dr. Müller GmbH	Bioplan Dr. Reinhold and Dr. Müller GmbH, Klein Machnow Director: Dr. Jürgen Reinhold

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Project sponsoring	Ministerium für Ernährung und Ländlichen Raum Baden-Württemberg, Stuttgart Bundesgütegemeinschaft Kompost e.V., Von-der-Wettern-Str. 25, 51149 Köln
Project processing	Ergebnisauswertung und Gesamtredaktion: Dr. Rainer Kluge, c/o LTZ Augustenberg, Nesserstr. 23 - 31, 76227 Karlsruhe
Collaborations	Teil „Bodenphysikalische Wirkungen“: Punkt C 2.2.2.1 Dr. Berthold Deller, LTZ Augustenberg, Nesserstr. 23 - 31, 76227 Karlsruhe
	Teil „Bodenbiologische Wirkungen“: Punkt C 2.2.2.2 Dr. Holger Flaig, LTZ Augustenberg, Nesserstr. 23 - 31, 76227 Karlsruhe
	Teile „Humusreproduktion“ und „Heißwasserlöslicher Kohlenstoff und Stickstoff des Bodens“: Punkte C 2.2.1.2 und C 2.2.1.5 Dr. Elke Schulz, Helmholtz Centre for Environmental Research - UFZ, Department of Soil Ecology, Theodor-Lieser-Strasse 4, 06120 Halle Dr. Jürgen Reinhold, Bioplan Dr. Reinhold und Dr. Müller GmbH, Stansdorfer Damm 39, 14532 Klein Machnow
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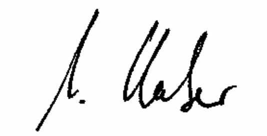
Preface

Besides the nutrient supply (fertilisation) adjusted to the plants' demand a sufficient application of organic matter (humus content) on soils and a lime supply (base balance) according to soil type and cultivation are the standard preconditions for the long-term ability to use agricultural soils which deliver high and assured yield. Qualitatively high-class and quality assured composts can provide here a valuable contribution. The utilisation of such composts for fertilisation and soil improvement in landscaping, in agriculture and for remediation of soils meanwhile is an example for a sustainable and ecologically compatible cultivation which simultaneously protects our limited resources.

Contracted by the Ministry of Rural Affairs of Baden-Württemberg as from 1995 static trials on compost application with a uniform test planning under real practice conditions were made in order to clarify extensively all relevant questions on the benefits of compost application in objective comparison with possible risks for the protection of soils, environment and consumers. In 2003 a first assessment of the test results was made on the basis of an associated research project “Compost Use in Agriculture”, which was sponsored by the German Environmental Foundation (DBU). The German Compost Quality Assurance Organisation Region South, the Agricultural Test and Research Organisation (LUFA), Augustenberg, the Institute for Agricultural Policy and Agricultural Market Education of the University of Hohenheim and the University of Applied Sciences, Nürtingen, Faculty Business Studies, as project partners were involved in the set-up of a research report in which all aspects of a sustainable compost application were evaluated ranging from pedological and horticultural fundamentals via economical and ecological assessments to the point of an effective compost marketing. The results of the report contributed essentially to the clarification of numerous discussions about pro and cons of compost use in agriculture.

As scheduled the five uniformly designed compost application trials were finalised in 2006. Thus 12 years of test results on three locations and 9 year test results on two locations are available - for Germany a unique basis and source for research and results. Once more the trials have been analysed thoroughly in an additional project on all parameters with relevance for crop cultivation and ecology. Besides the questions on humus management effects, the relevance of which become more and more important in agriculture, a special attention was turned on a thorough ecological final assessment of compost use which besides heavy metals includes a number of organic pollutants as well. The results are presented, discussed and assessed in this final report.

Our special thanks are going to the Ministry of Food and Rural Affairs Baden-Württemberg, which supported the long-term trials and enabled the cost-intensive final tests. We also express our gratitude to the German Compost Quality Assurance Organisation for the financial support of the pedological tests. Last but not least we thank all persons who were involved in the final project (see imprint) and the test supervisors who in a cooperative way contributed to the integral and substantiated presentation of the final report. May this final report with its comprehensive data basis and experiences and practice-related application recommendations support and optimise a sustainable use of quality assured composts in agriculture, horticulture and landscaping.



Dr. N. Haber, Director, Center for Agricultural Technology Augustenberg (LTZ)

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C/N-ratio	Ratio of the total amount of carbon and nitrogen	SchALVO	Ordinance for areas to be protected in the Region of Baden-Württemberg
$CaCl_2$ solution	Calcium chloride solution	HM	Heavy metals
CAL solution	Calcium acetate lactate solution	DM	Dry matter
C_{org}	Total organic carbon of soil	VDLUFA	Association of German Agricultural Analysis and Research Stations
C_{mic}/C_{org}-ratio	Ratio between microbial and organic carbon in the soil	DDD	Dichlordiphenyldichlorethane
C_{hwl}	Hot water soluble carbon content in the soil	DDE	Dichlordiphenyldichlorethylene
C_{inert}	Conversion carrier organic carbon of the soil	DDT	Dichlordiphenyltrichlorethane
C_{ums}	Metabolisable organic carbon of the soil	HCB	Hexachlorobenzene
FM	Fresh matter	HCCH	Hexachlorocyclohexanes
GUD	Total weed dominance	PCB	Polychlorinated biphenyles, selected congeners No. 28, 52, 101, 138, 153 and 180
N_{hwl}	Hot water soluble nitrogen content of the soil	PCDD/F	Polychlorinated Dibenzodioxins/ -furans
N_{inert}	Inert bound nitrogen content of the soil	PAK	Polycyclic aromatic hydrocarbons
N_{min}	Plant available nitrate nitrogen of soil layers 0 -90 cm in kg/ha N	FK	Field capacity
N_t	Total nitrogen content	nFK	Usable field capacity
N_{ums}	Metabolisable part of total nitrogen content of the soil	LK	Air capacity
OM	Organic matter	PA	Pore portion

Sustainable Compost Application in Agriculture - English Summary of the Report

1.0 Objectives and methodical concept

The objective of the environmental policy in the Federal Republic of Germany to recycle suitable biowastes predominantly on a material not on an energy basis continues to be of high priority. Intensive efforts are necessary to close material loops as far as possible in order to counteract effectively the increasing shortage of important economic and valuable resources for the maintenance of soil fertility in agriculture, landscaping and horticulture. Besides the protection of finite nutrient reserves, first of all phosphorous, is it necessary today to keep the humus contents of garden soils and in arable land on a sufficiently high level in order to guarantee their usability and to achieve high and qualitatively first class yields on a long-term basis.

Professionally produced composts proved to be suitable resources in order to cover the high demand for the cultivation of soils used in horticulture and agriculture - besides traditional sources like fertilisers from animal origin or straw and green manure. They are used more and more to improve soils and for fertilisation, mainly on farms without other alternative organic fertilisers.

Decisive for the utilisation of composts in agriculture is to observe reliably the principles of sustainability. That means composts must achieve a measurable use for plant production and/or soil fertility (utilisation aspects respectively beneficial effects) und simultaneously guarantee all interests to protect soils, environment and consumers in the medium and long term (risk assessment).

In the year 1995 the State of Baden-Württemberg, Germany established compost application tests with regard to these aspects. The objective of the project was to test all decisive aspects on cultivation and ecology of compost utilisation under real practice conditions in an objective view and on a science-based level.

A first circumstantial assessment of these compost tests until the year 2002 were made in a research project of the German Environmental Foundation (DBU) (final report - compare ANONYM 2003A). The five uniformly designed compost trials were finalised in 2006. Test results are available now for three locations over twelve years and for two locations over nine years - for Germany a unique basis and source for research and results.

The objective of the final project until 2008 was to provide a comprehensive assessment of a long-term compost application based on the 2003 intermediate report where all aspects - above all ecological aspects - on crop cultivation on arable land were tested. With the help of the additional test years the results and assessments of the 2003 project should be evaluated and the application guidelines for a sustainable compost use be modified - if necessary.

The innovative methodology and concept of the project was to carry out an integrated test of all beneficial effects and possible risks of compost application under *concrete practical test conditions with trials* on arable land following a consistent test concept (compare box below) and with the use of *quality assured composts* from the region. By means of an active involvement of farmers and compost plant managers in this project the results of the research work were completed and checked by practitioners so that for the follow-up compost application guidelines a high practicability could be guaranteed.

The active involvement of farmers and compost plant managers in this project caused the test results of the research work to be completed and checked by practitioners so that the application guidelines resulting in a highly practicable utilisation can be guaranteed.

Below the **compact information about the execution of the project**. For details considering concept, trials and testing compare chapter B 2 and B 3.2 in the Full German Report.

Test location	Five locations in the region of Baden-Württemberg, Germany: Forchheim - Fo, Weierbach - We, Stockach - St, Ellwangen - El, Heidenheim - He Predominantly on farm land (except Fo)
Soils	Predominantly intermediate-type and heavy soils, except location FO (= sandy soil)
Composts	Quality assured composts: biowaste composts (Fo, St, El, He) compost from green waste (We)
Test period	12 years (location Fo, We, St), 9 years (location El, He)
Test parameter	▪ Graded compost application: without (=control), 5, 10, 20 t/ha DM per annum ▪ Graded N-supplementing fertilisation: without, 50, 100 % of fertilizer optimum
Test design	Randomised block design, 12 alternatives with 4 repeated application each, in total 48 test lots
Crop rotation	All tests uniformly carried out: maize/winter wheat, winter barley, hereby grain maize (locations Fo, We), silage maize (location St, El, He)

The following chapters 2.0, 3.0 and 4.0 of the short report show the results of the final project in a compromised and focussed version considering their application in practice. Further analysis and assessments see chapter C in the full German report and its annexes 1 and 2.

2.0 Beneficial effects on crop cultivation

The results of the assessment of crop cultivation confirm the estimation in the DBU project report as of 2003 where the use of agricultural compost application (beneficial effects on crop cultivation) always results in *the sum of individual effects* finally reflected in the yield and in increased soil fertility. It became apparent that the effect of compost application - unlike the effects with mineral fertilisers - is slower and *can usually be measured not before several years.* Therefore is it necessary for a sustainable fertilising and soil improvement to apply compost regularly and over a longer period (3 to 10 years).

In the medium and long term the soil-improving effect of a regular compost application usually is more relevant compared with the effects of fertilisation. It is a result of the considerable application of organic matter and its positive impact on the humus content on the soil. This is clearly demonstrated by the long term field trials.

But the considerable application of nutrients and lime through the fertilising effects of compost offer additional valuable savings which allows reducing the costs for plant production.

2.1 Organic matter, humus reproduction of the soil and soil improvement

From the considerable supply of organic matter of annually ca. 2.4 - 2.8 respectively 3.6 - 4.0 t/ha DM with a compost supply admissible for crop cultivation of 20 respectively 30 t/ha DM every 3 years - favoured by the comparably high portion of stable, reproductively effective carbon (C) in the organic compost substance[1] - approximately 0.6 - 0.9 t/ha respectively 1.0 - 1.3 t/ha per annum carbon will be humus reproduction-effective in a short time (compare table 1). As a rule the humus content of the soil can be covered to a large extent, even at suboptimal humus contents. The balance is at least stable, however, positive, that means all in all the **humus balance** will be influenced positively (for details compare chapter C 1.1.2.1 in the Full Report).

Table 1 Supply of organic matter with compost and humus balance of the soil: average areas

Annual supply with compost		Compost supplies in t/ha DM 3 year rotation	
		20	30
Organic matter	t/ha DM	2.4 - 2.8	3.6 - 4.0
Carbon (C)	t/ha	1.3 - 1.7	2.0 - 2.4
Thereof C reproducible	t/ha	0.6 - 0.9	1.0 - 1.3
Annual humus demand of soil in t/ha carbon		Humus demand of soil	
		average	high
Humus content	optimal	0.2 - 0.4	0.6 - 0.9
	suboptimal	0.4 - 0.6	1.2 - 1.6

The humus contents of soils (top soil) proved this in all tests of compost application where the humus content could be increased effectively (compare chapter 3.2 and table 4). Usually the increasing compost supplies caused an extensive linear increase of humus contents, which were relatively independent from the added N-supply. Relatively low compost supplies of annually 5 t/ha after 9 respectively 12 years of test period provided measurable increases of humus contents of approximately 0.2 - 0.4 %. With annual compost supplies of 10 t/ha DM the humus contents increased even on an average of 0.4 - 0.8 %. Even higher increases could be measured with very high compost supplies of annually 20 t/ha DM which is, however, only important for soil sanitation (soils with extremely low humus supply). The increase of humus contents on sandy soils (location Forchheim) was slightly lower than on medium to heavy soils, caused by a high microbiological activity at comparably high temperatures.

[1] *On average approximately 50 % of the C content, compare BGK (2005)*

According to the available results an increase of the humus content in soils can be calculated within a dimension of 0.1 % per 8 - 9 t/ha DM of organic compost substance (compare details chapter C 2.2.1.2 in the Full Report)

As a rule the increase of humus contents was registered for top soils only. Yet, in some soil layers from 30 - 60 cm an increase could be observed, as well (compare chapter C 2.2.1.9 in the Full Report).

In all can be said that a compost application admissible by waste regulations and in regard of a possible crop cultivation of up to a maximum of 30 t/ha DM in a 3 year rotation are ranging beyond the necessary compost supplies for a simple humus reproduction. Therefore are they very suitable, as compost application tests confirmed, to build up a humus balance in soils and to optimise its humus contents. The tests proved that there was no increased degradation of organic carbon in soils, which could be expected following the recommendations of humus balancing for more easily degradable organic fertilisers. **Thus the tests proved distinctly a sustainable humus enrichment of soils at a regular compost application**. (Compare chapter 2.2.2). This emphasizes that compost application, facing scarce resources, will achieve higher importance through the considerable supplies of organic matter with a relatively high portion of reproducible humus above all in the market of crop farming with the usual high amounts of humus and especially at the restoration of soils poor in humus.

The lasting positive influence of the humus balance in soils proved to be the decisive precondition for **the soil-improving effects** of a regular compost application - this is underlined by the test results (compare chapter C 2.2.2 and table 33 in the Full German Report). Especially effective and more pronounced than during the test period could this be seen in the **soil-biological parameters** (compare chapter C 2.2.2.2 in the Full German Report). The soil-physical parameters, too, especially those of the water content, improved effectively during the test period (compare chapter C 2.2.2.1 in the Full Report).

For an overview of the project results of the compost application tests and their effects on land use compare table 2.

Among the parameters of the **soil structure** the *dry bulk density* respectively the *bulk density of the soil* has been distinctly reduced by the application of compost. On the other hand the total *pore portion* increased decisively with decreasing bulk density, but rarely on heavy soils. The loose compactness and the increasing pore portions of the soils improved drainage and aeration, these effects being a concrete advantage. The air capacity of soils can increase if pore portion and bulk density are improved. Less clearly, yet more often could be determined that the aggregate stability of the soils increased. This can be expected mainly on medium and heavy soils but rarely on sandy soils. Therefore compost application on medium to heavy soils with bad soil structures (soil compaction) is advantageous with a positive influence on the elasticity and capacity of the soils. They show an increased workability and according to farmers' opinion a reduced fuel consumption. The reduced erosion on slope areas is a result of increased humus contents which can be evaluated as a distinct beneficial effect.

Quite clear were the positive effects of regular compost application on the **water content** of the soil. *Water capacities* were normally distinctly improved. Especially on medium to heavy soils, an assured and significant increase of the water capacity could be seen, a smaller one on sandy soils in Forchheim.

This positive development can be in general detected as well in the *water content*, e.g. by an increase of absolutely 1 to 2 % demonstrated in the vegetation period of 2002 after compost has been applied. Similar is valid for the *usable field capacity* (nFC) - through the increase of the portion of medium-sized and coarse pores decisive for the "plant available" water content - which predominantly has been influenced positively. In all, the increased available water pool in the soils is one of the decisive beneficial effects of compost application what the three parameters proved. Crops are able to resist longer lasting droughts, mainly on light soils or on soils far away from ground water resources. Yet a possible increase of *water permeability* on soils with compost supply couldn't be allocated on measurement technique[2]. Observations in tests and by farmers ascertained a more rapid drying of soils treated with compost after heavy rainfall.

Especially advantageous is the significant stimulation of relevant parameters of **soil biology** after a regular compost application. With the help of the test results a sustainable and improved activity of the soil organisms on arable land could be ascertained by regular compost supplies, especially by supporting the transformation processes in the soil (mineralisation of organic matter, release of fertilising nutrients) - a result that has now been confirmed by farmers based on numerous field tests.

The portions of *microbial biomass*, the *N-mineralisation* and the *phosphatase activity* have been improved in a highly significant way during the test process. Hereby the development of the compost effect considering the microbial biomass and N-mineralisation was especially stronger than in the year 2002, this is an indication of the sustainable effect of long-termed compost supply. Of practical importance is the approved indication that N-mineralisation of soils after compost application was higher than it could be expected from the slightly increasing N-total contents.

The N-mineralisation equilibrium in the soil is moved obviously after several years of compost application - as the then higher N-utilization rates prove - through the activity of the soil organisms towards the soluble and thus fertilising effective N-portions. Thus the low N-load at the beginning (compare chapter 2.2) rises with the increasing application period. Of advantage as well is the assured increase of the phosphatase activity of the soil. This promotes the mineralisation of organically bound phosphorous portions in the compost doses. This indicates further the comparably high fertilising efficiency of the total P-supply with compost, which according to the tests can be completely credited to the P-utilization (compare point C 2.2.2 in the final German report) in the fertiliser balance.

Last but not least the *phytosanitary potential of the soil*, its ability to resist harmful organisms can be improved as well. This can be advantageous, as tests proved, e.g. for the suppression of fusarium in winter weed, by a faster degradation of infectious harvest residues. The experiences gained from the long term compost application trials confirm the overall impression that the support of soil biology reflects an essential portion in the gradual improvement of soil fertility achieved through a regular compost application.

[2] *The very high dispersions of individual results do not allow to deduce assured tendencies.*

Table 2 Soil improving effects of compost application: Summarised project results and experiences stemming from literature and practice

Parameter	Tendency	Effects on land use
		Soil structure
Aggregate stability	increasing	Primarily on medium and heavy soils: higher flexibility of soils, mechanical load capacity higher, improved protection against soil compaction and erosion
Pore portion	distinctly increasing	Increase the portion of medium-sized and coarse pores, improved aeration and drainage, improved gas exchange
Air capacity	increasing	
Storage density	distinctly decreasing	Soil loosening, pre-condition for improved aeration and drainage
		Water household
Usable field capacity	distinctly improved	Increased capacity for water storage, increased water storage at drought, increased protection of plant population against drought stress
Water content		
Water capacity		
Water infiltration	increasing (unassured)	Improved water passage at heavy rainfalls, avoidance of stagnant moisture, rapid drying of soil surface
		Microbiology of soils
Microbial biomass	distinctly improved	Sustainable activation of soil microbiological life, increased mineralisation of organic matter, thus increased nutrient release (above all N and P), increase of resistance against harmful organisms and physical soil loads **Altogether:** **gradual improvement of the soil fertility**
Phosphatase activity		
N-mineralisation		

2.2 Supply of nutrients and lime and their fertilising efficiency

2.2.1 Supply and fertilising balance

The medium **nutrient supplies** of a compost application suitable for crop cultivation of 20 to maximal 30 t/ha every 3 years are essential (compare table 3). If one considers the medium until high nutrient removal going along with harvesting of products, the relevance for the **medium nutrient balance** - which is essential for the fertilising calculation - can be assessed as follows:

- Nitrogen: at medium compost doses slightly negative to balanced, at high supply balanced to slightly positive, at high removals balanced, great fluctuations possible.
- Phosphor: on average mostly balanced.
- Potassium: at medium removals distinctly positive, at high removals negative, great fluctuations possible
- Magnesium: always distinctly positive.

The balancing of the nutrients also proves that with moderate and, above all, maximal possible compost doses thresholds can be achieved with all nutrients (N, P) and can be surpassed in the most disadvantageous case (low K removals, distinct with Mg). They have to be met in the sense of an equalised fertiliser balance (German Fertiliser Ordinance Requirements) in order to guarantee the nutrient balances in the short run for the benefit of soil protection and water conservation (details compare point C 1.1.2.2 and C 2.1.1.2 in the final German report).

Table 3 Annual supplies of nutrients and lime with compost doses suitable for crop cultivation

Annual supplies	**Compost doses** (t/ha DM) in a 3-years rotation		**Assessment**
	20 - average	30 - high	
Nutrients in kg/ha	Medium ranges		Average nutrient balance
Nitrogen - N	80 - 110	120 - 160	Slightly negative (medium doses) resp. balanced to slightly positive (high doses), at high removals balanced
Phosphorous - P_2O_5	35 - 55	60 - 80	Predominantly balanced
Potassium - K_2O	60 - 85	100 - 120	Removals medium: positive Removals high: slightly negative to balanced
Magnesium - MgO	35 - 60	60 - 85	Always highly positive
Valuables in dt/ha	Medium ranges		Average balance
Lime - CaO	2,0 - 4,0	3,0 - 5,5	Positive for lime balance, maintenance liming

The supply of alkaline effective substance with compost is considerable. Medium doses of 20 t/ha DM in a 3-year rotation can cover the lime loss on light soils. High compost doses of 30 t/ha DM in a 3-year rotation in any case meet the liming needs of medium to heavy soils as long as their ph values doesn't fall below suboptimal ranges. The lime supplies have the range of a *maintenance liming*. However, they are not sufficient for the restoration of acid soils (Details compare point C 1.1.2.1 and C 2.1.1.1 in the final German report).

2.2.2 Fertilising efficiency of the valuables and nutrients (besides nitrogen)

Besides the supplies finally decisive for an evaluation in the fertiliser balance is the **fertilising efficiency** of the nutrients and valuables. Here changes of the *humus and total N-contents* together with the *pH effects* (lime) (compare table 4) in the soil must be assessed. In addition the nutrients (phosphor, potassium, magnesium) but preference here has the influence of the *soluble i.e. plant available soil contents* which are decisive for the fertilising efficiency (compare table 5). The special case of the *"fertilising efficient N-portion"* of the total nitrogen supply of the compost application which is resulting from the special conditions of N-mineralisation of organic matter must be assessed independently.

Table 4 **Effects of compost application suitable for crop cultivation on the humus and total contents of N and the pH value of soils: Summarised project results after 9 respectively 12 test years, medium range**

Characteristics		**Humus content %**	**Total N-content %**	**pH Value**
Increase at an annual compost dose of (t/ha DM)	5	0.2 - 0.4	0.02 - 0.03	0.1 - 0.3
	10	0.4 - 0.8	0.04 - 0.05	0.3 - 0.6
	20	1.4 - 1.8	0.07 - 0.10	0.6 - 0.8
Uprating size		0.1 % per 8 - 9 t/ha DM of organic matter from compost	0.1 % per 8 - 9 t/ha DM of organic matter from compost	0.1 pH units per 10 dt/ha CaO from compost
Assessment		Reproduction of the organic matter assured	Total N-pool gradually rising	Dimension of maintanace liming

Humus and humus quality of soils

The definite effect of compost application in regular intervals on the *humus contents* of soils has been reported in detail under chapter 2.2.3. According to the test results a medium compost dose of 15 - 20 t/ha DM in a 3 year rotation is already sufficient to influence the humus balance positively.

Similar to the humus contents (total carbon contents - C_{org}) in soils, the carbon contents soluble in hot water (C_{hwl}) increased in general during the compost application trials with an increasing compost doses, especially on biologically active soils (compare chapter C 2.2.1.5 in the Full German Report) - this indicates an increasing mobilisation of the applied organic matter.

The *transformable portion* of the total carbon content (C_{ums}) showed hereby a development in the opposite direction dependent on the compost quality. As it decreased relatively with stable garden compost poor in nutrients it increased considerably with less mature fresh compost from biowaste. On the other hand the contents of *inert organic carbon (C_{inert}) low in transformation capability* increased definitely with an increasing compost application in all trials, especially on medium and heavy soils where mature composts were applied. This assured project result is a definite evidence for significant **humus enrichment in soils** with regular compost application, even if the level of an equal humus balance is surpassed[3].

Nitrogen, lime and main nutrients

The total N-contents of the soil increased in the course of the trials, however, only gradually, but measurable (details compare chapter C 2.2.1.3 in the Full Report). The total N-pool of the

[3] *According to VDLUFA position on „humus balancing" (compare point C 2.2.1.5 of the full report) one can assume that no lasting increase of the C_{inert} soil contents will be expected above an equalised humus balance. Apparently this is not valid for compost application.*

soil (dependent on the soil type of approximately 3.000 - 6.000 kg/ha N) is positively influenced in the medium term.

The determined uprating of

around 0.01 % per 500 kg/ha N from compost application

comes quite closely to the calculated rate of 0.01 % per 350 kg/ha. As only a small portion of N-supply of the applied compost becomes effective for fertilisation purposes (compare table 6), the increase of the N-pool must be observed critically, in order to avoid a too large positive N-balance necessary to protect soils and water bodies reliably.

The assessment of lime supply with compost applications in regular intervals as *maintenance liming* (compare table 3) is confirmed in the trials through the development of the *pH values* in the soil. In the medium-term are they at least stable respectively increased, even quite slowly (details compare chapter C 2.2.1.1 in the Full Report). As a magnitude an up-rating of

about 0.1 pH-units per 10 dt/ha CaO from compost application could be determined.

After the trials ended a pH stabilising effect of the compost application in deeper soil layers could be determined as well (compare chapter C 2.2.1.9 in the Full German Report). Compost doses suitable for crop cultivation of 20 to 30 t/ha DM in a 3-year rotation are definitely able to influence positively the lime balance of the soil. A lime consumption following a compost application in regular intervals, which could lead to a gradual decrease - as it was assumed quite frequently - can be excluded after these long years of trials. The considerable lime supply at excessive compost doses of 60 t/ha DM in a 3-year rotation can be of interest even for remediation measures with acid or degraded soils (dump soils) as the explicit pH effect of the trials proved.

Among the **main nutrients** the supply of phosphor and potassium applied with compost is decisively important for a fertilising efficiency. The trials proved for both nutrients that without a frequent basic fertilisation (compare figure 1) the soluble “plant available” contents of the soil - caused by harvesting consumption and erosion (mainly with potassium) - sank decisively. With a continuous compost application dose of 5 t/ha DM annually this reduction in contents could be compensated to some extent but could fully be balanced by an average dose of 10 t/ha DM. With very high compost doses of annually 20 t/ha DM increasing soil contents could be ascertained.

Therefore, at compost applications both nutrients show good plant availability and a high fertilising efficiency (see table 5).

Table 5 Plant availability and fertilising efficiency of the supply of main nutrients (phosphor, potassium, magnesium) with compost application in regular intervals

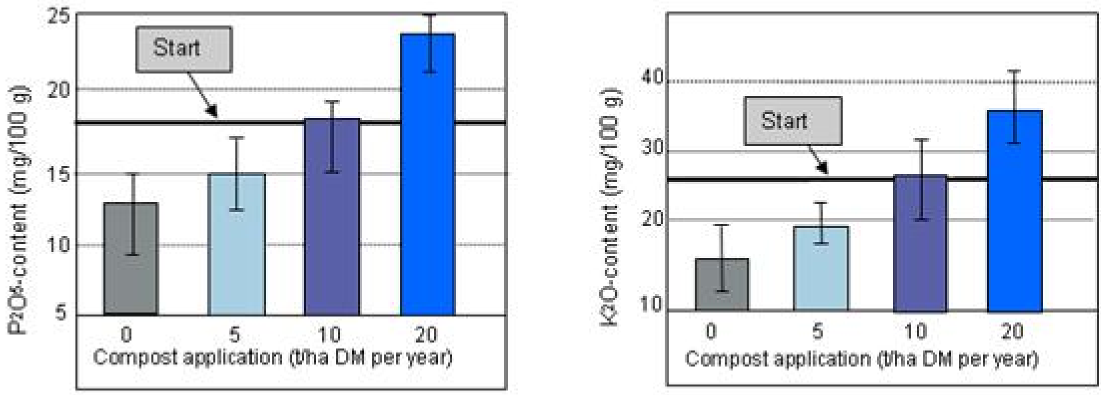
Assessment characteristics	**Main nutrients**		
	Phosphor	**Potassium**	**Magnesium**
Plant availability	High		Moderate
Soluble soil contents without supply	Declining	Strongly declining	Slightly declining
Soluble soil contents stable at compost doses of	20 - 30 t/ha DM in a 3-year rotation		Low reaction on compost application
Compost fertilising efficiency	High	High	Low
Accounting in the fertiliser balance	**Full accounting, thus usually the limiting factor for compost application!**		Medium-termed

Through compost application in regular intervals and in an optimal range for crop cultivation (20 to 30 t/ha DM in a 3-year rotation) the essential nutrients in the soil are balanced - this is distinctly approved by the trials - i.e. a decline of the contents available for plants can be avoided. They must be completely accounted to the fertilising balance. Through this the supplies can form the limiting factor for compost application, if, e.g., the level of the plant available soil contents is already in a high range (German soil fertilisation level D = high and E = very high) where a further fertilising is not allowed, following the regulations of the German Fertiliser Ordinance. .

Contrary to this the plant availability and effects of the compost application on the soluble magnesium contents of the soil can be looked upon as being relatively minor. Slight increases could be recognised in all test locations by the end of the trials. Despite of the classified low fertiliser efficiency the high positive balance considering magnesium (see table 3) is not a disadvantage, but definitely an advantage considering the fact that it counteracts the permanent Mg leaching and by all means the soluble Mg portion in the soil cannot achieve phototoxic limits (for details about the soluble main nutrients compare chapter 2.2.1.6 in the Full Report).

The distinct increase of soluble phosphor contents in the tilled topsoil is continued in a diminished way in soil layers of 30 - 60 cm. In layers of 60 -90 cm any compost impact could rarely be found. These evidences barely apply to potassium and magnesium, i.e. no measurable compost effects could be observed in deeper soil layers. An essential conclusion for a sustainable soil protection is that with an *appropriate compost application dose in crop cultivation* no risks exist for a reduction of soil fertility respectively for the protection of soil and the water body with a compost dose of 20 to 30 t/ha DM in a 3-year rotation, e.g. by an undesired leaching of nutrients in deeper soil layers i.e. in the groundwater (compare chapter 2.2.1.9 in the Full Report)

Fig. 1: **Example for the development of „plant available" soil contents of phosphorous (left) and potassium (right) dependent on compost application doses.**
Average of all test locations towards the end of the trial series4
Bars = means of the compost doses in the years 2004 - 2006;
Range = 25th resp. 75th quantile of the single values; Start = Content at start of the trials
(Location Fo, We, St: 1995 - 1997, Location El, He: 1998 - 2000)



It can be finally said that the fertilising-efficient nutrient supplies of compost application doses suitable for crop cultivation show considerable and valuable **saving potentials** for the farmer. Thus the phosphor and potassium supply replaces a basic fertilisation. The lime supply corresponds to a maintenance liming.

2.2.3 Humus quality and accountability of nitrogen to the calculation in the fertiliser balance

In contrast to the main nutrients phosphor and potassium - as the trials proved in correspondence with the observations of the farmers - only a low contribution of the relatively high total nitrogen (N) supply can be accounted to the N fertiliser balance. This is subject to the relatively strong fixation of nitrogen in organic matter which is also reflected in the *small soluble N-portions* of just 3 to 5 % (mean value) of the total N amounts of composts (compare the individual results in chapter C.1.1.1 and table 18 in the Full Report) Therefore the fertiliser efficiency of the N-supply of compost application doses decisively depends on the special conditions of the N-mineralisation of organic matter, which, besides the ability to mineralise (easily / heavily degradable organic compost matter), can be influenced by further factors, above all by the microbial activity of the soil, the climate conditions and the cultivated crop type and the period of vegetation.

Comprehensive analyses about the humus quality of the soil after compost application led to very interesting new findings (compare chapter C 2.2.1.5 in the Full Report):

The nitrogen content in soils soluble in hot water (N_{hwl}) increased in all trial series with an increasing compost application dose analogous to the carbon content (C_{hwl}) soluble in hot water, especially explicit in trials with silage maize in the crop rotation.

[4] *Locations Forchheim (= Fo), Weierbach (= We) and Stockach (= St): after 9 to 12 test years*
Locations Ellwangen (= El) and Heidenheim (= He): after 6 to 9 test years.

Hereby, the *metabolisable portion of the total nitrogen (N_{ums}) in the soil* has been influenced more distinctly by compost application dose than the metabolisable portion of the organic carbon (C_{ums}). The metabolisable nitrogen portions - representing the size of the potentially mineralisable N-contents in the soil - achieved values of 30 - 40 % of the total nitrogen in the soil during the trials with a crop rotation of silage maize, in trials with grain maize values even considerably higher than 50 %. Apparently high compost doses had a balancing effect on the behaviour of releasing nitrogen in soils: As in soils with lower N_{ums} portions of the total nitrogen assured increases of the N_{ums} values could be detected, the N_{ums} portions at an increasing compost doses decreased with high initial values.

The *inert portion of the total nitrogen* in the soil (N_{inert}) that stays in the soil for a longer time without being essentially included in the internal material turnover in the soil, was increased, statistically assured, by all used composts. The increase was especially apparent with the application of mature composts. This result explains and emphasizes the assessment gained on the basis of the N-extraction during harvest that with compost application in regular intervals *only a relatively low fertilising contribution of the total N-supply* must be calculated.

Circumstantial results are now available from the long-term trial series - gained over the period of several crop rotations on different soils and under different climate conditions - enabling a differentiated and practice related evaluation of the **N-utilisation** from compost application doses. Following from this the fertilising effective N-portions of the total N-supply with compost application for practical conditions, i.e. with a *regular supplementary N-fertilisation*, should be accounted to the calculation of the fertilising balance as follows (compare table 6 and for details chapter 2.4.1):

Short-termed, i.e. after an *initial* compost application and for a period of up to three years only 3 to maximal 5 % of the N-supply per annum can be accounted as efficient for the fertilising calculation. This low rate means that the additional N-fertilisation must be applied without any deduction according to "good agricultural/fertilising practice". Under favourable conditions (high soluble N-portions in the compost, high N-consumption of the plants) the N-utilisation rate can increase up to 10 % per annum as well. In this case a corresponding lowering of the regular N-supplementary fertilisation must be considered. With unfavourable conditions above all with green composts rich in its wooden portion (fresh composts) a temporary N-immobilisation can occur, which has to be met by corresponding additions with the N-fertilisation.

Medium-termed with a *regular* compost application from the 4th year on up to the 12th year (second crop rotation and upwards) higher N-utilisation rates of annually 5 - 12 % can be credited to the fertilising calculation. That means, in a 3-year rotation an average of

> approximately 20 - 35 % of N-supply of a compost application dose becomes efficient regarding fertilisation (!).

At very favourable conditions, e.g. type of crop with strong N-consumption (some vegetable types, silage maize and similar) locations with high turnover and composts with high N-supplies and good N-availability (e.g. mature bio-composts) maximum utilisation rates of 15 - 20 % per annum of the last application dose are possible. These high annual rates must be necessarily accounted in the N fertilising balance, i.e. the normal N fertilisation must be reduced correspondingly so that a surplus of soluble N-portions does not arise in the soil.

Where just a low N-mineralisation takes place - e.g. at green and fresh composts - not more than 5 % of N-supply annually must be credited to the fertiliser balance, in order to avoid an insufficient N-supply to the plants as a follow up of a possible N-immobilisation and in the most unfavourable case a yield loss.

Table 6 Ranges of N-portions efficient for fertilising through composts to be attributed to the N-fertiliser balance Valid for compost doses of 20 to maximal 30 t/ha DM in a 3-years rotation

Annual total N supply absolute (kg/ha)		
	Average	90 - 130
	Range	50 - 180
N-portion p.a. to be accounted in the fertilising balance (% total N supply)		
- Short-term (1 - 3 years)	Average	0 - 3
	Range	-5 - 10
- Medium-term (4 - 12 years)	Average	5 - 12
	Range	0 - 20

N-portion to be accounted into the N-fertilising balance (explanation):

Lower values:

- Composts with low soluble N-portion (normally green composts, fresh composts)
- Crop rotation with low/medium N-consumption (e.g. all types of corn)

Upper values:

- Composts with high soluble N-portion (normally biocomposts, mature composts)
- Crop rotation with high N-consumption or a long vegetation period (e.g. silage maize)

The tests clearly proved that with regular compost utilisation in a cumulative time of application an increasing N-mineralisation from the organic compost substance takes place. This is the result of the co-operation of several factors, like the humus enrichment and the growing microbiological activation of the soil - which little by little positions the mineralisation equilibrium towards higher soluble N-portions - supported by the supplementary N-fertilising.

The supplementary N-fertilisation can be more exactly quantified by a possible increase of the N_{min}-contents in the soil in addition to the N-utilisation rate as a *result of compost application*. This is normally achieved at the planning of N-fertilisation based on regional or measured values gained especially at the location. If such guide values are not available an **increase of the N_{min}-contents with a compost application** by a supplementary N-fertilisation should be assumed based on the trial experiences (see chapter C 2.2.1.4 in the Full Report) with an

average of 5 to 15 kg/ha.

Higher values of up to 25 kg/ha are possible (compare table 9 and chapter 4.2 below).

2.2.4 *Final assessment*

As a summary the results described in in chapter 2.0 “Beneficial effects of crop cultivation” above prove that a medium to long term efficiency of a regular compost application causes a sustainable improvement of all of the tested physical and biological parameters and humus contents of the soil. The essential properties for land use for crop cultivation like workability, soil activity, water holding capacity and a reduction of erosion showed a positive development. These beneficial effects are completed by a supply of nutrients and lime resulting in a valuable cost saving potential. This supports the soil fertility in general and finally the harvest yield as well (compare chapter C 2.5 in the Full German Report), which by an intensive plant production can achieve a yield increase of 5 to 10 %.

3.0 Possible risks

To see the conception integrally a decisive target of the compost project was to test all of the risks of compost application entirely and impartially, besides the relevant beneficial effects. A sustainable and environmentally acceptable compost application in crop production can be stated only if the terms of environmental protection (of soils and the water body) and consumer protection (high-class vegetable food) can be guaranteed in the long run.

The compost application trials offered a valuable and solid basis with their standardised tests and analyses consequently carried out over years. All questions consider*ing the risk assessment of compost application* which were raised and discussed in the public by experts during the last two decades have been verified with these field trials - partly in very extensive and costly test programs. The trials included mainly the following points:

- Situation with heavy metals: contents and loads of compost application doses,
  impacts on soils and harvest products;
- Organic harmful matter: comprehensive monitoring of contents in soils;
- Epidemic and phytohygiene: situation in composts;
- Weed seeds: quantity in composts and soils;
- Foreign matter and stones: situation in composts and
- N-Mineralisation: assessment of potential positive N-balances of soils, effects on N_{min}-contents.

In the following the **results of a risk assessment** are presented which is based on comprehensive scientific results and examined - including literature results and experiences in practice - considering concerns in the public. The target is to examine potential risks relevant (incl. ranking) for the environmental and consumer protection in order to finally present an integrated judgement.

3.1 Undesired material

3.1.1 Heavy metal situation

The undesired heavy metal contents (Pb, Cd, Cr, Ni, Hg) in quality assured composts fall distinctly below the limit values of the German Biowaste Ordinance, as comprehensive studies prove (compare table 7 below and chapter C 1.2.1.1). The heavy metal levels are on average below 30 %, in the most unfavourable case (90 % of all results) below 50 % of the limit values. This guarantees an essential precondition for sustainable soil protection with the use of compost. Higher exhaust rates with Cu and Zn, on an average of 50 % of the threshold, in unfavourable cases below 80 % can be tolerated, as long as the geogenic soil contents are below background values - which may never be surpassed - and no considerable increase of the soil contents is resulting from the minor supplies due to the compost use.

Due to minimal heavy metal removals of the plants (by harvested products) a positive balance always remains in the soils which is *absolutely small* and can be calculated regarding soil protection. This can clearly be seen in the total contents of heavy metals in the soil (compare table 7 below and chapter C 2.2.1.7? in the Final German Report).

The contents of undesired heavy metals (Pb, Cd, Cr, Ni, Hg) didn't rise during the field trials after 9 respectively 12 years of compost application - even not at excessive high compost application of annually 20 t/ha DM, i.e. *the double* of the maximally admissible compost dose. Only the Cu and Zn contents showed a slightly increasing tendency at a dose of more than 10 t/ha DM annually into the topsoil which, however, is not analytically assured regarding the spreading caused by soils. The deeper soil layers (30 - 60 cm and 60 - 90 cm) showed no changes in the heavy metal content after compost application of several years. (compare point C 2.2.1.9 in the Full German Report). A relocation of heavy metals in the soil profile is all but impossible as the tests proved.

The DBU (German Federal Environmental Agency) 2003 project report proved that the mobile heavy metal contents in soils stayed unchanged with Pb and Cr and declined even distinctly with Cd, Ni and Zn on account of the decreasing solubility on account of the increasing pH values after compost application. The mobile Cu-content showed in individual cases slight increases. Dangers through considerable mobilisation of heavy metals after compost application are not relevant according to these results.

In view of constant total contents of heavy metals and a generally missing mobilisation, regarding Cd, Ni and Zn even decreasing mobilisation, the **heavy metal contents in harvest products** stayed unchanged during the trials compared with control without compost (compare table 7 below and chapter C 2.3.2.1).

Pb, Cd, Cr and Ni even showed slightly lowering values. Thus an endangerment by heavy metal supplies on the quality of foods produced from plants fertilised with compost in regular intervals can be virtually eliminated according to these long-term trial results.

Table 7 Heavy metal situation after long-term compost application in crop cultivation: summarised results. Valid for compost dose which are optimal fro crop cultivation of 20 t/ha in a 3 years rotation

<table>
<tr><th colspan="4">Heavy metals</th></tr>
<tr><th>Composts</th><th>Medium range</th><th>90. Quantile</th><th>Assessment</th></tr>
<tr><td colspan="4">Contents[5] in % of the limit values of the Biowaste Ordinance[6]</td></tr>
<tr><td>Hg</td><td>10 - 15</td><td>25</td><td rowspan="2">Low exploitation of the limit values</td></tr>
<tr><td>Pb, Cd, Cr, Ni</td><td>20 - 30</td><td>40 - 50</td></tr>
<tr><td>Cu, Zn</td><td>40 - 50</td><td>65 - 80</td><td>Medium exploitation of the limit values</td></tr>
<tr><th>Soil contents</th><th>Changes in 9 - 12 years</th><th colspan="2">Assessment</th></tr>
<tr><td colspan="4">Total contents in top soil[7]</td></tr>
<tr><td>Pb, Cd, Cr, Ni, Hg</td><td>Unchanged</td><td colspan="2">Not desired heavy metals → medium-term (10 - 30 years)
No risk of critical soil contaminations</td></tr>
<tr><td>Cu, Zn</td><td>Minimally increasing</td><td colspan="2">Increase of 2 (Cu) respect. 4 mg/kg (Zn) rarely critical as they are simultaneously essential trace nutrients</td></tr>
<tr><td colspan="4">Total content soil profile (30 - 60 cm, 60 - 90 cm)</td></tr>
<tr><td>Pb, Cd, Cr, Ni, Cu, Zn, Hg</td><td>Unchanged</td><td colspan="2">No risk of a critical soil contamination by dislocation of heavy metals, not even with Cu and Zn</td></tr>
<tr><td colspan="4">Mobile contents[8]</td></tr>
<tr><td>Pb, Cr</td><td>Unchanged</td><td colspan="2" rowspan="3">No risk of critical harmful heavy metal mobilisation,
but decline caused by pH increase in the soil</td></tr>
<tr><td>Cd, Ni, Zn</td><td>Declining</td></tr>
<tr><td>Cu</td><td>Minimally increasing</td></tr>
<tr><th>Plant contents and removals</th><th>Changes in 9 re-spectively 12 years</th><th colspan="2">Assessment</th></tr>
<tr><td colspan="4">Plant contents</td></tr>
<tr><td>Pb, Cd, Cr, Ni, Cu, Zn</td><td>Unchanged, indi-vidually declining</td><td colspan="2">No risk of critical harmful heavy metal contents, declining at Cd, Ni caused by pH increase of the soil</td></tr>
<tr><td colspan="4">Heavy metal removal by harvest products in % of the compost supply[9]</td></tr>
<tr><td>Pb, Cr, Ni</td><td>< 5</td><td colspan="2" rowspan="3">Heavy metal balance always distinctly positive, however supplies are absolutely low</td></tr>
<tr><td>Cu, Cd</td><td>5 - 10</td></tr>
<tr><td>Zn, Hg</td><td>10 - 30</td></tr>
</table>

[5] *German-wide analysis and survey of the BGK: years 2005 and 2005, random inspection: ca. 5.700 compost samples*

[6] *Limit values of German Biowaste Ordinance for compost application doses of 20 t/ha DM in a 3 years rotation.*

[7] *Results of compost application trials: status after 9 - 12 years test trials*

[8] *Results in the DBU 2003 project report: status after 8 years of trials*

[9] *Supply with 30 t/ha compost in 3 years*

Finally can be concluded that a slight increase of the heavy metal contents in soils - examined over very long periods - cannot be excluded in absolute terms considering the positive balance of heavy metals at a compost application of high doses in regular intervals. A risk assessment with the available objective facts proves distinctly that a possible risk is lower-ranking and thus controllable and calculable. The process of soil accumulation runs very slowly and can be analytically determined not before 10 - 20 years at minimum. With soil analysis[10] in wide intervals can be reliably guaranteed that such increases cannot arise without notice. Risks by irreversible, harmful soil contamination definitely don't exist.

The loads of Cu and Zn are not only of disadvantage given to the fact that both heavy metals are *essential trace nutrients* which are urgently needed by the plants. In contrary those - definitely low - loads are desired in soils with low contents of trace nutrients, as they are contributing to a sufficient supply for the plants (regular fertiliser doses of these trace nutrients show by the factor 5 - 10 higher levels!). As far as geogenic background values and limit values of soils according to the German Biowaste Ordinance are distinctly falling below this regulation, the Cu and Zn loads of a compost application in regular intervals are in any case tolerable.

However, the permanent task remains to take care of the heavy metal content in soils - in the sense of a precautionary soil protection - so that they won't deteriorate by a compost application. For this purpose the heavy metal supply with compost must be lowered as far as possible ("minimising request"). Furthermore compost should be only applied on soils which go below the precautionary values of the German Soil Protection Ordinance.

3.1.2 Organic pollutants

Long-term frequent analyses on persistent PCB and PCDD/F of the composts applied in the trials proved that the contents have been very low, ranging close to the background level (compare table 8 below and chapter C 1.2.2 in the Full German Report). Correspondingly the contents in the soils, regularly fertilised with compost, remained unaffected in the field tests, even at an excessive compost application dose of annually 20 t/ha DM. They are ranging at the background values of unloaded soils (PCB - < 2 µg/kg, PCDD/F - 1 to 2 ng I-TEQ/kg, compare chapter 2.2.1.8 in the Full German Report).

By the end of the compost project soil samples were additionally tested on a series of organic pollutants which during the last years had been discussed in relation to soil protection. The result of the very costly tests for the organic pollutants group (organochlorine pesticides, PAH polycyclic aromatic hydrocarbons, phtalates, organo-zinc compounds, chloride phenols, nonyl phenols, bisphenol A, musk compounds) proved that the long-term compost application had no influence whatsoever on these materials not even with an excessive application doses (compare table 8 below and chapter 2.2.1.8 in the Full German Report). The soil contents showed an absolutely low level, mostly in the range of the analytical detection limits respectively of the background values of unloaded soils.

[10] *They are mandatory according to the German Biowaste Ordinance*

Table 8 **Organic pollutants after long-term compost application in crop cultivation: summarised project results. Valid for optimal compost application in crop cultivation of 20 t/ha DM in a 3 year rotation.**

Organic pollutants		
PCB and PCDD/F	Medium range	Assessment
Compost[11] contents in % of the assessment value[12]		
PCB	20 - 30	Very low, near to background level; load from compost application is **without problems**
PCDD/F	35 - 45	
Contents soil	Uninfluenced	In the range of the background load (PCB <2 µg/kg, PCDD/F 1 to 2 ng I-TEQ/kg); **No influence** from the long-term compost application detectable
Further organic pollutants	Number of individual compounds	Assessment
Contents in soils after the end of the trials		
Organochlorouspesticide	29	- Contents mostly at a low level (µg/kg), mostly in the range of analytical detection limit respectively of the background values - PAH in the range of reference values for unloaded soils **Totally:** Throughout **no influence of a long-term compost application detectable**, neither with excessive application doses
PAH	20	
Phthalates	10	
Organo-zinc-compounds	10	
Chlorphenoles	27	
Bisphenols A	1	
Nonylphenole	3	
Musk compounds	2	

In total the compost application trials showed that there is no indication for an enrichment of organic pollutants in the soils resulting from a compost application in regular intervals. No corresponding risk exists according to the available extensive data collection.

3.2 Further potential risks

The **N-mineralisation** of the organic matter incorporated in the soil with compost runs slowly and thus controllably. This is proved extensive examination during the 9 to 12 years trial period. Thus the **soluble N-pool** in the soil is *only gradually increasing*. Following the trial results (compare table 9 below and chapter 2.2.1.4 in the Full German Report) an increase of the **N_{min}-contents due to compost application** under the conditions of a supplementary N-fertilisation can be estimated

on average with 5 - 15 kg/ha.

[11] *Results from compost application trials, random inspection from 54 compost samples*

[12] *Guide values absolute: PCB - 200 µg/kg DM, PCDD/F - 17 ng I-TEQ/kg DM - 1/6 of limit values according to German Sewage Sludge Ordinance.*

Higher values of up to 25 kg/ha are possible. The solid N-fixation in organic matter guarantees that no sudden release of soluble nitrate portions and leaching into groundwater occurs.

Table 9 Further possible risks of a long-term compost application in crop cultivation: abbreviated results valid for compost application doses optimal for crop cultivation of 20 t/ha in a 3 year rotation

Further potential risks			
N-surplus of compost application		Medium range	Assessment
Increase of N_{min}-contents in kg/ha		5 - 15	- **No rapid**, ecologically risky increase of the soluble N-pools in soils - N-leaching controllable
N-leaching from the soil		Minimal	
Impurities and stones (% DM)	Medium range	90. quantile	Assessment
Impurities >2 mm	0.08 - 0.13	0.35	- Distinctly lower than limit values[13] - Compost nearly free of impurities, low stony portion
Stones >5 mm	1.0 - 1.5	3.5	
Epidemic and phytohygiene	Assessment		
Microbiology Bacteria and fungus in composts	High numbers of bacteria of 10^6 - 10^8/g FM and high fungus portions of 10^4 - 10^7/g FM advantageous, supports microbiological activity in soils		
Epidemic hygiene - Pathogens responsible for human diseases (salmonella) - Coliform germs	With **orderly intensive first decomposition part of composting** - salmonella **couldn't be found** - coliform germs: predominantly < guide values **No risk** for the hygienic quality of the harvested products		
Phytohygiene Pathogens of plant diseases	**Not existing** at an orderly intensive first decomposition part of composting		
Weed seeds and infestation - Weed seeds in composts - Weed infestation on arable land	- Weed seed in compost: at an orderly intensive first decomposition part of composting **virtually not existing** - Weed infestation on arable land: **no increased weed infestation** found in trials (54 rating years!) compared with the control without compost		

Such a risk doesn't exist virtually if the supplementary N-fertilisation is reduced by the amount of the N-exploitation rate of the compost dose and by the average increase of N_{min}-contents - i.e. a mean of around 10 - 15 % of the N-supply - necessary for crop cultivation.

Impurities and stones are no longer a problem when quality assured composts are used. The contents of impurities > 2 mm are below a mean value of 0.1 % DM (median values) and are distinctly below the limit value according to the German Biowaste Ordinance even in the most unfavourable case (90. quantile) (compare table 9 and chapter C 1.2.3 in the Full Report). However, for the acceptance of compost in crop cultivation is it essential that it is *free of*

[13] Limit values according to German Biowaste Ordinance: impurities >2 mm = 0,5 % DM, stones >5 mm = 5 % DM.

impurities above all free from plastic foils[14] which can massively damage the visual appearance after compost was applied, although no danger for soils and harvested products exists.

Stones compared with other undesired materials can be classified as a lower-ranking risk. An average of the monitoring tests showed stone portions of >5 mm in composts 1.0 - 1.5 % DM.

The **epidemic hygiene and phytohygiene of composts** utilised in crop cultivation, i.e. the absence of risky epidemic and phytohygienic pathogen contents (indicator micro-organism salmonella) and pathogens of plant diseases, is always guaranteed - as numerous tests proved (compare table 9 above and chapter C 1.3 in the Full German Report) if a state of the art first hot decomposition stage in the composting plant (at least 65° C over a period of 7 days) has been realised. Random samples from composts in this project proved that the contents of coliform bacteria ranged below the harmless guide values as well. High total contents of bacteria and fungi were detected with same samples. They are indicators for the biological activity of composts which promotes the corresponding microbiological activity of the soils.

The number of **germinable weed seeds and plant propagules** in composts show harmless ranges if a state of the art intensive first hot decomposition stage is realised in the composting plant - an essential pre-condition for any compost use in agriculture (compare table 9 above and chapter C 1.2.4) This is proven by a comprehensive survey in analyses carried out in the frame of the German compost quality assurance scheme. It showed a mean value of 0.09 germs/l fresh matter - a value which ranges by dimensions below the limit value of the German Biowaste Ordinance of 2 germs/l fresh matter. Thus quality assured composts are virtually free from germinable weed seeds and plant propagules. This was confirmed by annual observations of the weed stock on the test areas. The result of 54 (!) annual ratings of the total weed ground cover degree showed in no case a measurable weed stock which could have been attributed to compost application. Farmers, using compost regularly, confirmed this result as well. The often expressed concerns that an increasing weed infestation on arable land would result from compost application could be rebutted manifold on an expert level and is not relevant.

3.2.1 Final assessment

The summing-up of the results of this comprehensive and holistic research compost application project concludes that potential risks of compost utilisation in crop cultivation as a whole are low and calculable if composts are used according to the "codes of good agricultural and fertilising practice", i.e. according to the needs of the soils and crops. This applies, above all, to the heavy metals and harmful matter situation. The risk of undesired heavy metal accumulation in the soil is, as long-term field tests proved, lower-ranking and thus controllable. Concerns in this regard expressed in the past by the expert from of soil and water protection organisations combined with demands for a tightening of the corresponding limit values proved to be subject to overreactions, because they didn’t reflect objectively the conditions in reality.

There are no virtual risks for the soil caused by actual contents of organic pollutants relevant for the environment. The same is valid for the epidemic hygiene and phytohygiene and weed

[14] *For this purpose the German BGK e.V. has introduced for the quality assurance of composts a further assessment parameter determining the portion of plastic foils.*

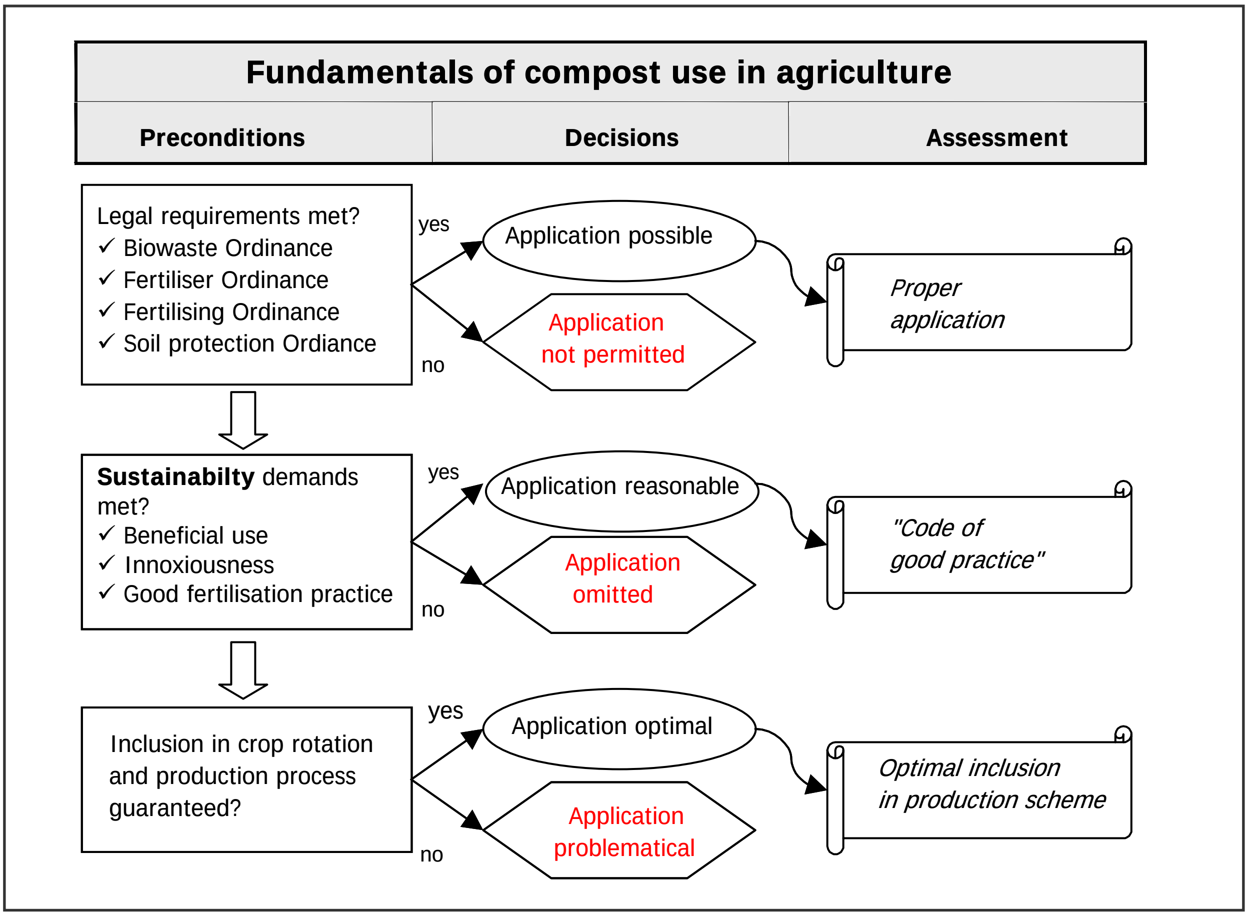
seeds, however, only under the pre-condition that a state of the art intensive first hot decomposition of composts took place in the compost sites. A potential risk of some relevance - if at all - is the N-mineralisation. It must be controlled by suitable parameters, like the soluble N-portion of the total N-content of the compost and the N_{min} contents of the soil, in order to avoid reliably undesired nitrate releases in the soil.

4.0 Sustainable compost application - fundamentals and recommendations for application

4.1 Fundamentals and decision-making

A sustainable compost application means to meet certain pre-conditions and application regulations for the use of composts in the agricultural crop production, thus combining the necessary requirements to protect the soil and environment with the advantageous and beneficial effects to guarantee reliably a harmless compost utilisation over long periods.

Fig. 2: Basics of Compost Application in Agriculture



The fundamentals of compost application in agriculture can be summarised as follows (compare figure2/box 1):

- *Correct application* → a compost application in crop cultivation is basically only possible if the requirements of the German Biowaste Ordinance are met. Moreover composts and their application - like all other fertilisers - are subject to the regulations of the German Fertiliser, the Fertilizing and the Soil Protection Ordinance.
- *An optimal integration into the production systems of crop cultivation:* → The advantageous effects can only be realised to their full extent if the compost application is optimally integrated in crop rotation and the production system (soil cultivation and others).

A further aspect is to use composts on locations with a best possible benefit (optimisation of benefits)

- „*Good codes of practice*“ → sustainable compost application also means that besides a harmless use all aspects of a beneficial use, i.e. a professional application as a fertiliser according to the rules of “good codes of practice” and the German Fertiliser Ordinance are guaranteed[15]. If this is not the case an application should be omitted.

In order to realise a sustainable compost application for a definite practice case the following **Guideline for Decision-making** should be consulted:

Starting with the decision-making “SOIL” (see figure3/box 2) a **first step** means to *check whether it is actually permitted* to apply compost on the intended farmland area. For this purpose the heavy metal contents of the soil must fall below the limit values according to the German Biowaste Ordinance. It would be even better if they are ranging within the precautionary limit values according to the Soil Protection Ordinance. If the limit values will be surpassed a compost application is basically not permitted[16]. This applies accordingly if a compost application on certain areas is forbidden on account of area restrictions (e.g. on grass land, simultaneous application of sewage sludge within three years).

In a **second step** it must be checked according to the Fertiliser Ordinance whether and if yes which definite fertiliser need is relevant for the soil and the crops to be cultivated and to what extent it can be covered by a compost application (“Assessment of the benefit”). The objective here is to calculate the fertiliser demand of the main nutrients (phosphorous, potassium, magnesium) and lime together with the humus demand of soils. The recommended compost quantity of annually 7 to maximal 10 t/ha DM depends on the fertiliser demand of the main nutrients according to the Fertiliser Ordinance, which is determined by the expected yield and the fertilising effective nutrient portion in the soil. But recently coverage and optimisation of the humus demand of soils is an increasing main focus of compost application above all in soils with suboptimal conditions.

A demand for organic matter from compost becomes relevant if the humus balance is negative, often in cash crop growing farms with their intensive production and straw removal and where the humus contents of the soil falls below the optimal values for individual soil types. On the other hand the compost application should be limited with soils with a very high humus contents except for soils with an existing risk of erosion. In the first instance compost becomes effective and beneficial at **bad soil conditions**, like a suboptimal soil structure (e.g. soil compaction), an insufficient water household (e.g. too low water holding capacity respectively useable field capacity), too low soil activity (e.g. insufficient microbial biomass, too low activity of rain worms etc.) and last but not least with rising risks of erosion.

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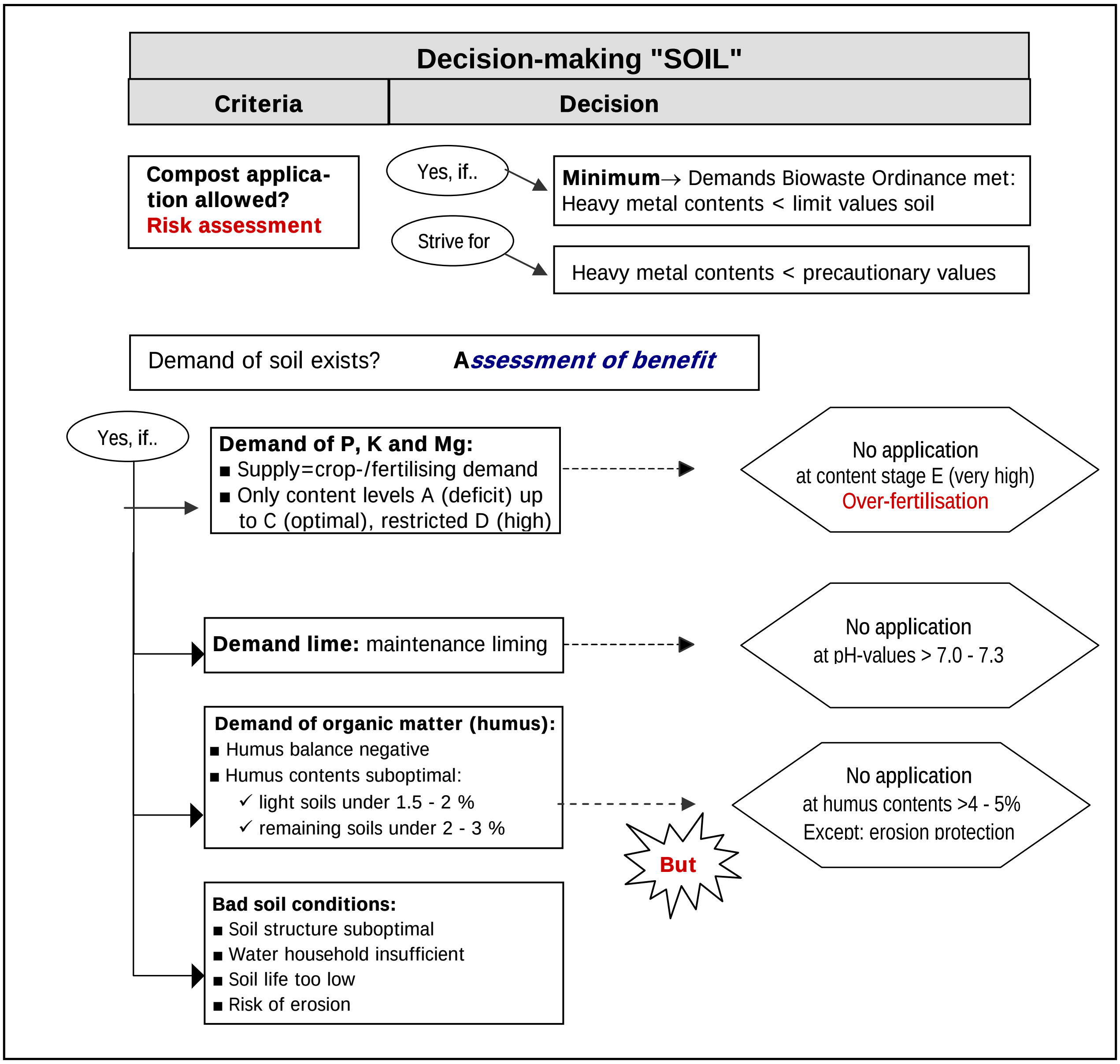
[15] The „good codes of practice“ of fertilising according to the German Fertilising Ordinance is also valid for the application of composts, which are normally labelled as organic fertilisers. Findings of this project should be considered in recommendations for application and for the further development of the good codes of practice of compost application.

[16] If the heavy metal limits in the soil of an already loaded geogenic region were passed a compost application through the competent authority according to §9 (4) Biowaste Ordinance could be allowed, if no further increase of the given heavy metal contents of the soil arises. This is guaranteed as far as the heavy metal contents of the composts, related to the inorganic residue (volatile residue), don’t fall below the corresponding soil contents.

Fig. 3: **Compost application in agriculture: decision-making "SOIL"**



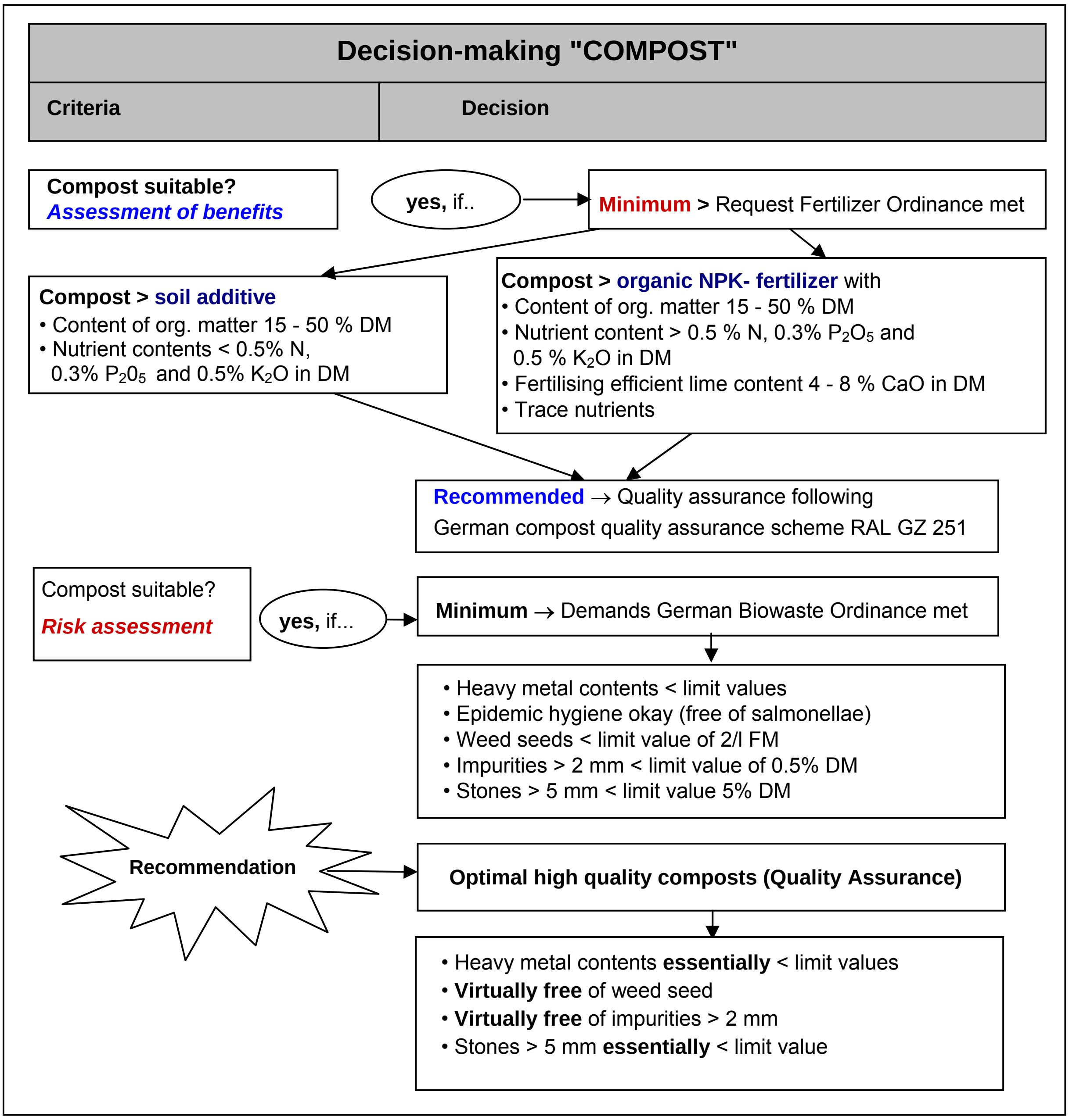
The project results demonstrated clearly that on account of the high portion of reproducible carbon in composts a sustainable humus accumulation takes place in the soil, even if the level of an equalised humus balance is exceeded.

With a compost application in regular intervals the **fertiliser demands of the main nutrients** (phosphor, potassium, magnesium), can at least partly, in most cases fully, be covered, i.e. if the supply of the soil is insufficient (German soil fertilisation status Classes A and B) or sufficient (Content class C). As a rule the supplies of phosphor and potassium are forming *the limiting factor of compost application* on account of their optimal fertiliser efficiency (can completely be accounted to the fertiliser balance!). In order to guarantee an equalised fertiliser balance compost must - like other fertilisers as well - be used restrictedly only in Content Class D and not at all in Content Class E, in order to avoid safely a possible over fertilisation combined with the risk of the leaching of nutrients (among all potassium!).

Finally the **lime supply** with a compost application must be considered, usually at the size of a conservation liming. A compost application must be omitted with very high pH values in order to avoid further pH increases on areas used for pH crop cultivation.

In a **3rd step** of decision-making the suitability of the composts to be applied must be clarified (compare figure 4/box 3). For this purpose only composts can be taken which fulfil the standards of the Fertiliser Ordinance of organic **NPK-fertilisers** (nutrient content >0.5 % N respectively. K_2O and >0.5 % P_2O_5) or **organic PK-fertilisers**. With lower nutrient contents composts must be classified as **soil additives**.

Fig. 4: Compost application in agriculture: decision-making "COMPOST"



Quality assured composts can provide a safer compost application, especially when risk criteria are guaranteed. In this connection the main criteria - besides the fulfilment of the standards of the Biowaste Ordinance - are that the heavy metal contents are clearly below the limit values, the composts are free from impurities >2 mm (values about 0.1 mm and lower), show only a small amount of stones >5 mm and contain no weed seeds and as the result of an orderly intensive first hot decomposition are showing a proper epidemic hygienic and phytohygienic status.

Quality assured composts are regularly and independently monitored. The details of the compulsory declaration of goods are surpassing the obligatory statements of the labelling of the Fertiliser Law. By this way the application is assured according to good professional practice and damages on account of incorrect application will be avoided.

4.2 Rules for application

A sustainable compost use with high application safety depends essentially on the fact that composts are applied *according to assured rules* - besides all mandatory test criteria according to chapter 4.1 above as precondition. All belonging and relevant frame conditions had been assessed in this compost application project and aligned with the practice experiences of farmers and the present literature.

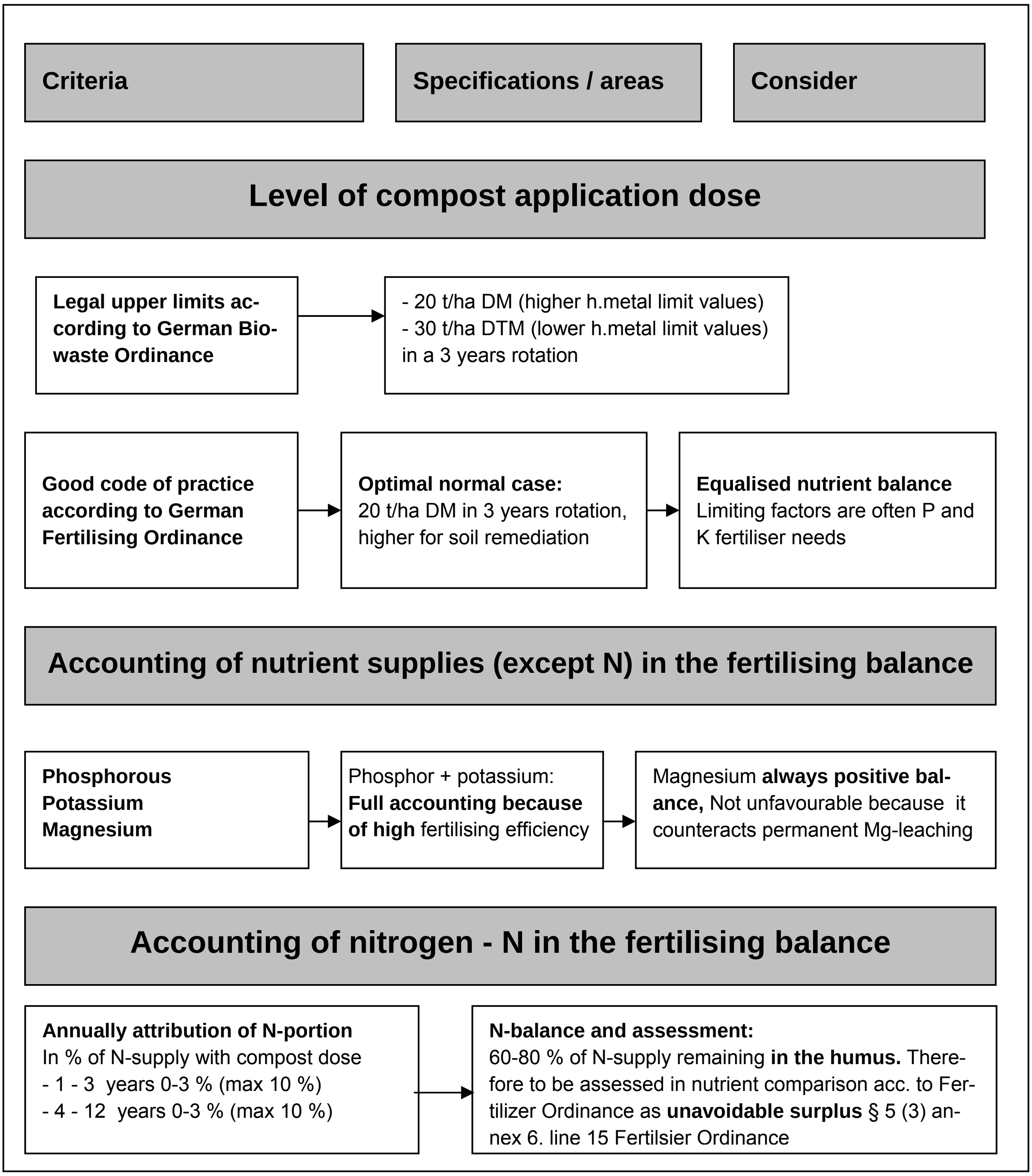
As a result the following **rules for a sustainable compost application** must be respected in agricultural crop cultivation (see figure 5/box 4):

Decisive for the amount of compost applied according to the Fertiliser Ordinance is the *warrantee of an equalised nutrient balance* in the frame of crop rotations. Hereby the upper dose limits according to the German Biowaste Ordinance of 20 respectively 30 t/ha DM in a 3-years rotation must not be passed. According to the rules of “good codes of practice” the optimal compost dose, whereby positive balances of phosphor and potassium rarely arise, lies around 20 t/ha DM that corresponds to approximately 30 - 40 t/ha FM. At unfavourable soil conditions (structural problems etc.) higher compost doses up to the upper level of 30 t/ha are allowed, in exceptional cases even higher, sometimes reasonable to achieve an efficient and quick soil improvement.

The **supplies of the main nutrients phosphor and potassium** are *to be fully credited* to the fertiliser balance on account of their good fertilising efficiency in order to avoid reliably positive balances. The unavoidable positive balance of magnesium (the supply is always exceeding the smaller crop consumptions) is not disadvantageous, as the project results showed, because it counteracts the permanent Mg-leaching and also cares for a gradual increase of the plant available Mg soil contents.

In order to guarantee optimal harvest yields compost doses must always be combined with a supplementing N-fertilisation (mineral and/or organic) because the fertilising efficient N-portion of composts is very small. The **annually accountable N-portion of the total N-supply from compost** to be credited to the fertiliser balance amounts in average to a maximum of only 3 % at a short-term compost application (in favourable cases; e.g. high soluble N-contents of the compost up to 10 %). At a long term compost use higher amounts of N-portions of annually 5 - 12 % can be accounted (in favourable cases up to 20 %).

Fig. 5: **Rules for sustainable compost application in agricultural crop cultivation: Level of compost application doses and accounting of the nutrient supply**



Therefore a positive N-balance beyond the admissible amount according to the German Fertiliser Ordinance is inevitable. However, tolerable from the aspects of soil and water protection, because 60 - 80 % of N supply is fixed in the humus medium-termed and is mineralised only gradually. Not only the slowly increasing N_{min} contents prove this but also the increasing portions of inert Nitrogen N_{inert} of the soil after a continuous compost application.

The above mentioned annually creditable N portions of the total N supply[17], which at a regular compost application slowly increase, must be considered. The remaining positive N-balance from compost application must be assessed as an *unavoidable surplus* according to § 5 (3) annex 6 (line 15) of the Fertiliser Ordinance. There is no question that this N-surplus must be kept low by suitable measures in crop cultivation[18].

The following **application periods and technical advices** for the compost application proved to be successful in practice (compare table 10):

Basically, compost should be spread at the start of the plant growth period. Hereby decisive is the good workability of the arable land, in order to avoid soil compaction through unfavourable conditions (e.g. wet soils). A convenient **application time** suitable for corn and root crops is before sowing respectively planting.

For winter cereals or catch-crop it has to be guaranteed that in periods with low nutrient consumption (autumn/winter) no considerable nutrient surplus arises which tends to be leached, - among all nitrogen. Fresh composts with a wide C/N ratio are therefore especially suitable for an spreading in autumn as during the winter season they will temporarily bind soluble nitrogen and prevent leaching thus conserving nitrogen for the beginning growth period in springtime.

Longer lasting frost periods in January and February proved to be very suitable for a *frost application of compost* in due time and spreaded in an even distribution without the risk of any critical soil compaction. Furthermore the darker soil surface caused by the compost layer provides a more rapid warming of the top soil caused by increasing insolation in spring thus supporting plant growth. Therefore it is recommended for the legislator to extend the exemption considering lime fertilisers on frozen and snow covered soils according to § 3 (5) clause 2 German Fertiliser Ordinance also on composts.

Among the **technical advices** for compost application the spreading intervals are the key aspect. The cumulated application of up to 30 t/ha DM in a 3-years rotation will be the usual case in agriculture on account of costs and spreading technique reasons because it guarantees low costs and *less traffic* on arable land. The fertilising efficient supplies of phosphor and potassium correspond to a storage fertilisation which is common at a basic fertilisation.

From the crop cultivation point of view the accumulated compost application is hardly advantageous as long-term tests proved. In the first application year the one-time high compost supplies cause considerable nutrient surpluses with increased leaching risks. The first crop will receive an unnecessary “luxury supply” of nutrients while the supply for the susequent crops will decline. An annual compost application which had proved to be superior during the long-term trials cannot be practised. A compromise of a 2-year rotation can be recommended if this is acceptable on account of cost reasons.

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[17] All of them imply the soluble N-portion and the increasing N-portion, which results from the mineralisation of organic matter (humus).

[18] The N-surplus according to the German Fertilizer Ordinance applies only to the N-fertilizer demand of the crops. In fact the larger part of the total N-supply from compost application remains in the organic matter and enters the soil via the humus reproduction gradually in the humus content of the soil. This "N-surplus" needs to be evaluated as essential need and can't be equalised with the fertilising efficient N-surplus according to German Fertilising Ordinance.

Criteria	Regulations	Consider
Suitable application periods		
▪ Before seeding resp. before planting	Winter corn / catch crop: August - September Silage maize/grain maize: March - April Potatoes/sugar beets: February - March	Fresh composts for suitable autumn spreading: Fixation of the residual nitrogen during winter time
▪ Frost application	January - February Winter cereal: application on tillered areas without problems	Advantages: No soil compaction, faster soil warming
Technical rules and advices		
▪ Application intervals	Accumulated every 3 years Advantage: lowering of application costs Annually respectively 2-years rotation Advantage: continuous supply of nutrients and valuables, more balanced nutrient balances, sustainable efficiency	**Possible disadvantages of accumulated application:** Discontinuous supply of valuables materials and nutrients, for first crop nutrient surplus and leaching risks, smaller supply for second crop.
▪ Application process	Incorporate evenly (5 - 10 cm deep) At erosion risks: also **mulching** without incorporation	**No ploughing of compost!** Problem: rotting, damages of roots

Suitable technologies for spreading are in practice the same as the ones for solid farm manure. Basically composts should be incorporated in soils only evenly (maximal 5 - 10 cm deep) in order to promote efficient transformation under air supply. Important is to avoid deep incorporation (with a plough) because this supports rotting processes under anaerobic conditions which can damage the roots. In order to avoid soil erosion a mulching layer from coarse compost without incorporation has proved to be successful.

5.0 Sustainable compost application - Final assessment

Long term compost application trials proved impartially that composts with their combined efficiency as humus and nutrient suppliers are able to contribute beneficially and sustainably to soil improvement and soil fertility.

Compared with other organic resources (e.g. liquid farm manure, digestion residues, untreated plant residues) qualitatively high-class composts showed to be the “best option”. As a rule they outclass other organic resources on account of their total benefits e.g. of their reliable hygienisation, their high portion of stable humus, the good fertilising efficiency with phosphor and potassium and their lime effect. Even potential risks - this is demonstrated by the long-term practice trials without any doubt - are nowadays low, can be calculated and don’t oppose an environmentally safe utilisation. A precondition for a sustainable compost application is, however, that the proven rules of the “good codes of practice” are consequently applied.

Composts proved to be especially efficient at the humus reproduction on arable land. Their importance in agricultural crop cultivation will presumably increase further, also in the face of an increasing demand of organic fertilisers (e.g. increasing cultivation of “energy crops” with high humus consumption, like maize), because the resources of organic matter for a sustainable humus reproduction on arable land run short through an increasing competition stemming from the demand for renewable energy production.

The provision of "recycling" fertilisers from closed loop waste management, like composts, becomes more and more important because the costs for commercial fertilisers were steadily increasing during the last years, and will increase further in future caused by increasing energy costs (e.g. for nitrogen production) and shortage of natural resources (primarily phosphate). The utilisation of phosphate in the closed loops is essential because there are no alternatives for this nutrient in contrast to energy.

Finally is it a matter of economical and ecological rationality to use composts first of all for agricultural crop cultivation because they meet the demands on a sustainable closed loop waste management in an optimised way.

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