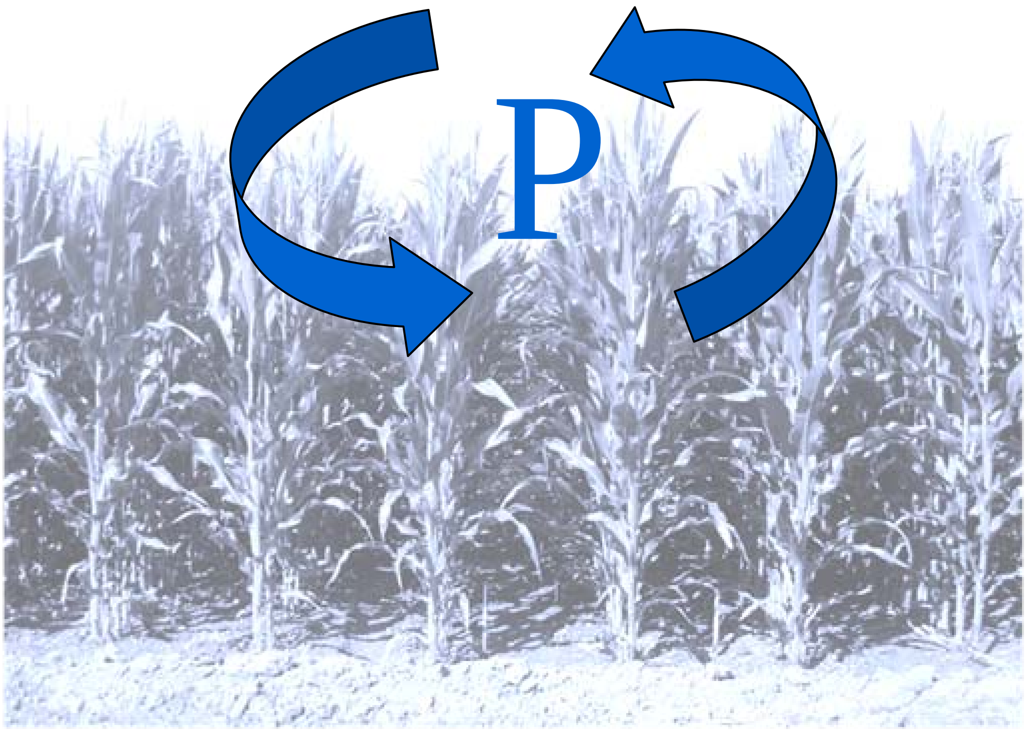
Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Requirements for agricultural use of recycled phosphorus

Bettina Eichler-Löbermann & Ewald Schnug



Global P “problems”

Limited P resources

Unbalanced P supply

P losses from agriculture

World-wide P-reserves are linked to the development of future agricultural needs and efficiency.

Universität Rostock
Traditio et Innovatio

Julius Kühn-Institut

P fertilizer use

	Agricultural area (1000 ha)	P consumption (t, P2O5)	P2O5 kg/ha
Africa	1157486	790745	**0.68**
_Western Africa	285326	63283	**0.22**
America	1197258	12264233	**10.2**
_Northern America	478997	6084086	**12.7**
_Central America	126280	564330	**4.46**
_South America	580185	5594762	**9.46**
Asia	1662869	22434693	**13.5**
_Central Asia	282461	56714	**0.20**
_Eastern Asia	678368	12419492	**18.3**
_South-Eastern Asia	117660	2086499	**17.7**
Europe	474273	4463090	**9.41**
_Western Europe	54590	1027059	**18.8**

FAOstat 2007

Universität Rostock Traditio et Innovatio

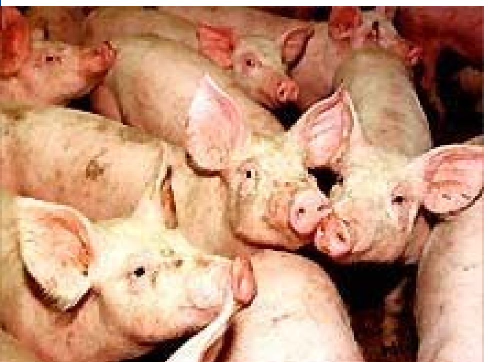
JKI Julius Kühn-Institut

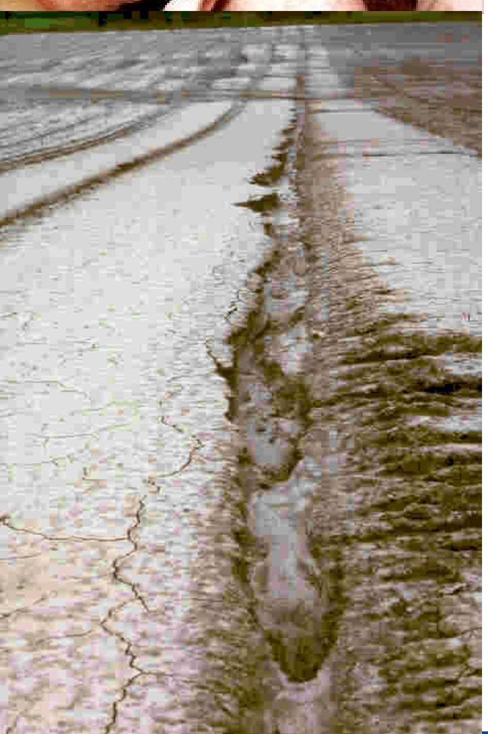
P balances

P-balance of different farm types in Germany (kg ha^{-1} P) (Frede 2003)

	Farm type		
	Arable	Forage	Livestock
Input	13	17	41
Output	22	12	20
Balance	-9	5	21

P losses





60% of the total P load to waterbodies in Germany are non-point losses with agriculture being the greatest contributor with 90%.

Waterbodies are sensitive against high P loads because of a limited buffer capacity.

Excessive algae growth and cyanobacteria (blue-green algae) are a serious threat to human health.

Universität Rostock
Traditio et Innovatio

JKI Julius Kühn-Institut

Residues as fertilizers

Manure, slurry
Carcass
Meat bone meal

Sewage sludge

Crops residues
Food industry residues

Ashes
Biogas slurries

Slag
….

+

nutrients
organic material
liming substances
advisory service
no waste disposal

-

heavy metals
organic xenobiotics
sanitation

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Residues as fertilizers

Overall objectives:

– consumer protection,
– production of healthy food,
– water and soil protection

– ecological and economical benefit by nutrient cycling

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Potential of P-recycling of P-containing secondary raw materials

Secondary raw material	Industrial Process	P (%)	P (t yr^{-1})
Slags[1]	Steel production	≈ 0.22	4,146
Lime residues[1]	Gelatine production	1.5 (d.w.)	306
Starch waste water[1]	Processing of potatoes	0.05	273
Defecation lime[1]	Purification of thick-juice in sugar beet	0.2	2,684
Sewage sludge (d.w.)[2]		2.4	**49,424**
Carcass meal[3]		3.1	**13,093**
Meat bone meal (MBM)[3]		6.1	**9,477**

[1]Werner (1997); [2]BMU (2007), Rosyadi (2003)

annual P demand of German agriculture - 560,000 t.

Full P recovery from sewage sludge, carcass and meat bone meal could satisfy about 13% of the total P demand.

Sewage sludge

Organic xenobiotics with existing thresholds and reference values for sewage sludge

HCB, -HCH, DDT and metabolites, Arom. halogen. Hydrocarbons, 1.4-Dichlorbenzol (1.4-DiCB), Decambromdiphenylether, Chlorphenols acc. to EPA, Phenols acc. to EPA, Pentachlorphenol (PCP), aliphatic hydrocarbons, Chlorinated paraffine, ads. organic halogens (AOX) halogen. hydrocarbons with trichloroethane, dichloroethane, trichloroethane, chloroform, tetra, Phthalates, total, DEHP, Tensides, total, Alcylbenzylsulfonate (LAS), Nonylphenol, Organotin compounds, Tributyltinoxide, polychlorinated biphenyls PCB, Terphenyls, Chlophen, A40 + A60, PCDD/PCDF, total, polycycl. arom. hydrocarbons (PAH/PAK), Benz(□)pyren, Benzol, toluol, xylol BTX, total, Mineral oils

Organic xenobiotics impose a serious, incalculable and irreversible threat to soil fertility and human health!

➡ **incineration destroys the organic compounds**

Sewage sludge

Chemical compostion of P-fertilizers and sewage sludge ashes (Haneklaus et al. 1998)

Product	Solubility	P (%)	Cd	Cr	Cu	Ni	Pb	Zn
					(mg/kg)			
Triple phosphate[4]	100% in water	22	30.6	300	23	31	< 1	448
Hyperphos[5]	80% in FA[1] 20% in conc. acids	13	46.3	245	-	15	-	400
Sewage sludge ash (A)	2.1% in AC[2] 8.2% in AC + CA[3]	6.5	4.1	330	911	132	325	2,513
Sewage sludge ash (B)	3.3% in AC 9% in AC+CA	5.2	3.1	177	1,301	69	168	2,695

[1]FA = Formic Acid; [2]AC = Ammonium Citrate; [3]CA = Citric Acid; [4]Boysen, 1992

(Texte Umweltbundesamt 55/92, research report 10701016/01, UBA-FB 92-104; [5]Heiland (1986): MSc thesis, Fachbereich Chemie, Hamburg)

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Meat bone meal

EU regulation No. 1774/2002 permits the co-incineration of carcass meal in coal fired plants.

Meat meal of category 2 and 3 can be applied as NP fertilizers.

Category 2 material may contain non-transmittable diseases and residues of medicinal substances.

.

Incineration of MBM destroys pathogens and preserves P!

Animal carcass incinerator

(Defra 2008)

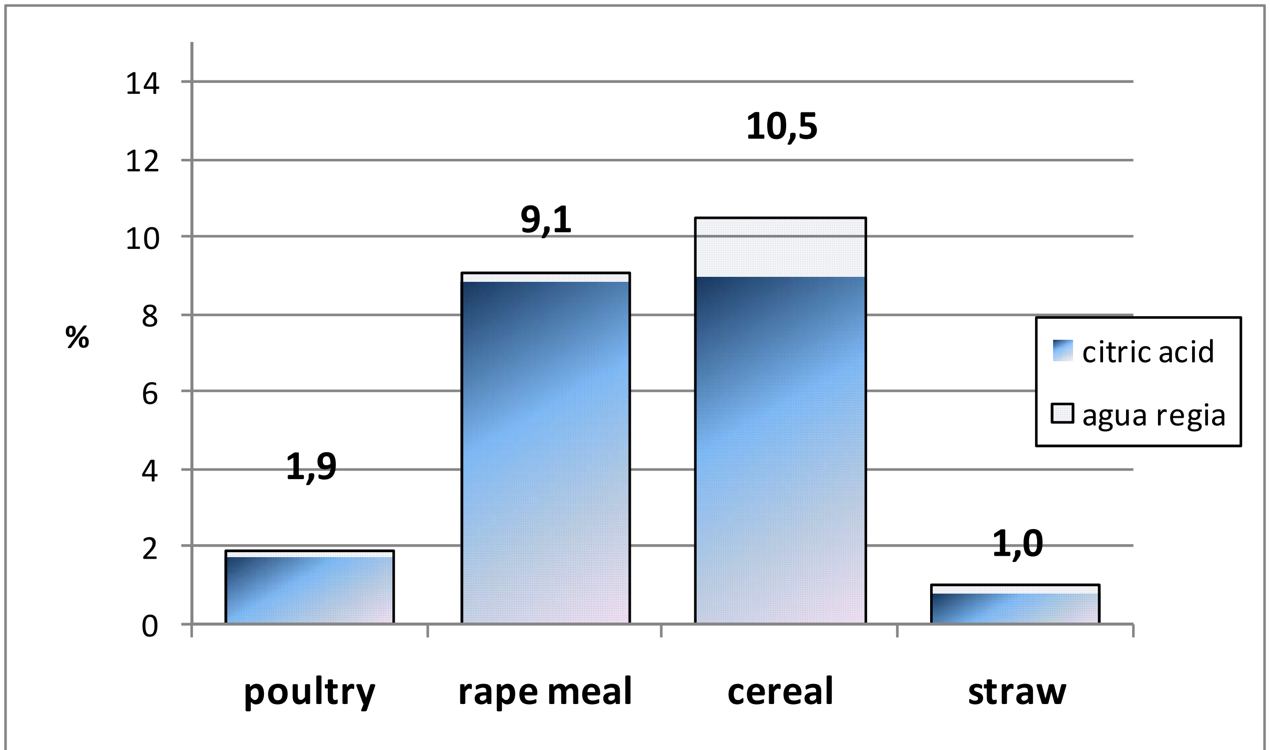
Crop biomass ash- P

Crop biomass ash is the oldest mineral fertilizer in the world

Type of ash	P content %
bagasse ash (Jamil et al. 2004)	0.01
alfalfa stem ash (Mozaffari et al. 2002)	0.9
horticulture ashes (Zhang et al. 2002)	0.04 - 1
wood ashes (Erich & Ohno 1992, Saarsalmi et al. 2001, Hytönen 2003)	0.9 – 1.7
wheat straw ash (Hytönen 2003)	1.3
rape straw ash (Hytönen 2003)	2.1
poultry litter ashes (Yusiharni 2001; Codling et al. 2002)	5.0
cereal ash (Eichler et.al. 2009)	10.4

Crop biomass ash- P

P content in ashes and solubility in citric acid (Eichler et al. 2008)



Poultry, rape meal: University of Rostock, Faculty of Mechanical Engineering and Marine Technology
Cereal: Department of Agricultural Education, Provincial Government of Lower Austria (Austria)
Straw: Leibniz Institute for Agricultural Engineering in Potsdam-Bornim

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Crop biomass ash- HM

Element mg/kg	wood (natural)	wood (treated)	wood Rostock	grain Rostock
Cu	164	6914	90	171
Co	21	21		
As	4	17		-
Ni	66	180	21	13
Cr	325	470	43	14
Pb	14	2144	200	3
Cd	1	20	0,2	1
Hg	0.01	0.5	0.05	0.04
Zn	432	1234	720	750

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Biogas residues

Nutrient content of slurry and biogas residues (% of FM)

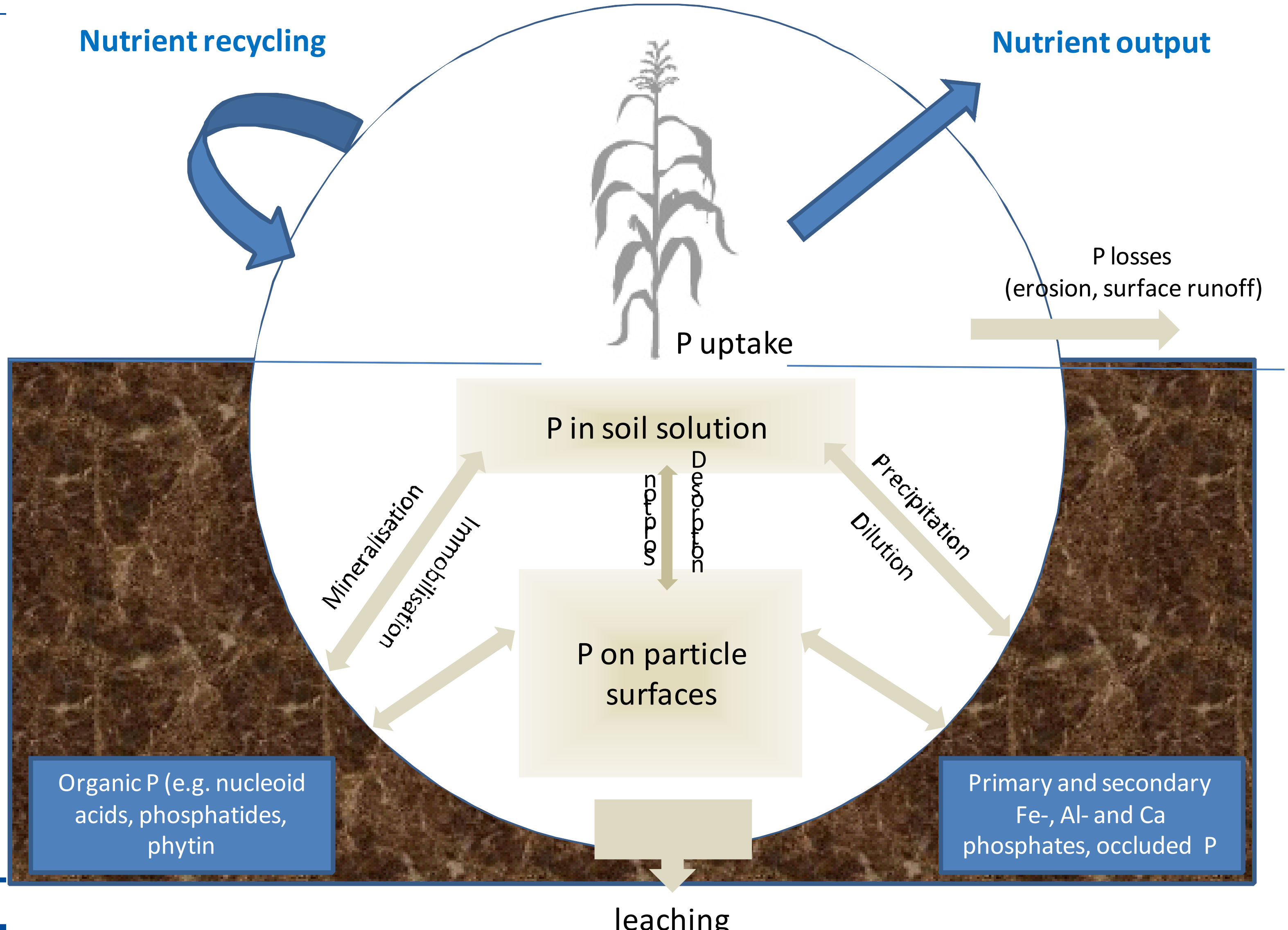
substrate	DM	OM	N	NH_4-N	P	K	Mg
dairy slurry	9,3	7,5	0,46	0,23	0,08	0,32	0,07
BR dairy	8,1	6,3	0,50	0,25	0,08	0,33	0,07
BR pig	4,2	3,1	0,46	0,35	0,07	0,20	0,05
BR maize	11,3	8,5	0,64	0,30	0,16	0,47	0,09

BR Biogas residue, DM dry matter OM organic matter

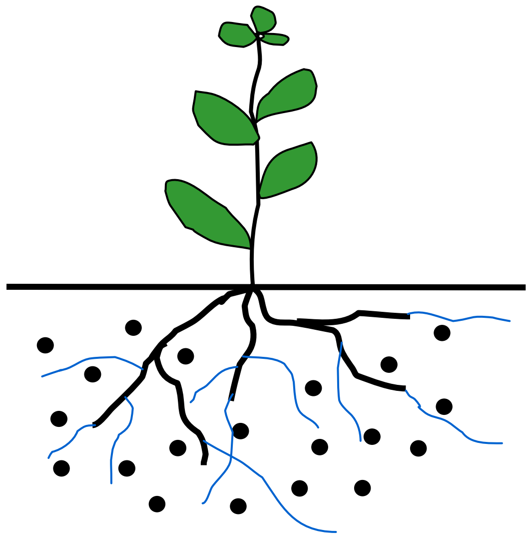
Biogas residues contain mainly less degradable org. compounds

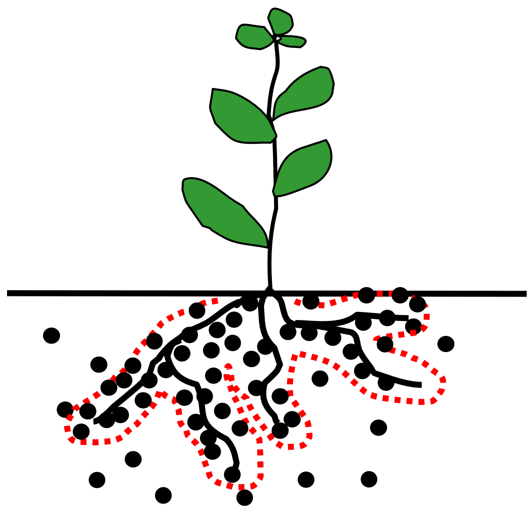
Universität Rostock

Traditio et Innovatio



Crops P mobilization





morphological
Enhanced spatial availability

- Enhanced root:shoot ratio
- Elongation of root hairs
- Enhanced formation of fine roots
- Enhanced mycorrhizal colonization

physiological
Enhanced chemical availability

changes in rhizosphere chemistry (pH; redox potential)
release of organic acids and enzymes

modified: Neumann & Römheld 2002, Hahn 2005

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

Results - Crop biomass ash

Effect of biomass ashes on soil P pools

Treatment	pH	Pw mg kg^{-1}	Pdl mg kg^{-1}	Pt mg kg^{-1}	Pox mmol kg^{-1}	DPS %
Control	5.31	8.59	30.3	516	11.9	40.1
TSP	5.30	12.98	39.0	533	12.6	41.8
Rape meal ash	5.41	12.53	38.8	534	12.8	42.4
Straw ash	5.52	12.84	41.6	526	12,4	41.9
Cereal ash	5.34	12.79	39.7	530	13.1	43.2
KCl	5.22	8.23	31.6	509	12.2	40.6
p	*0.024 **	*0.000****	*0.000****	*0.003***	*0.000****	*0.000****
LSD (0.05)	*0.11*	*3.01*	*6.63*	*15.0*	*0.55*	*1.20*

Pot experiment 2007, 6 kg soil per pot, after 6 weeks (Schiemenz & Eichler, 2009)

Soil P contents were also affected by crop cultivation

Universität Rostock Traditio et Innovatio

JKI Julius Kühn-Institut

Crop biomass ash

Treatment	maize	rape	rye grass	barley	lupin	phacelia	oil raddish	b.wheat
Control	100	100	100	100	100	100	100	100
TSP	146	145	141	133	131	128	120	113
Rape meal ash	133	142	141	126	142	137	116	118
Straw ash	122	129	115	117	108	136	85	109
Cereal ash	134	114	130	104	103	129	120	123
KCl	94	101	85	113	109	116	97	110
p (duncan)	0.000***	0.000***	0.000***	0.000***	n.s.	0.039*	0.004**	n.s.

rel. values, pot experiment 2007, 6 kg sandy soil, Sign. interactions crop x fertilization, 2-factorial anal. of variance

Combination biomass ash x P solubilizing green manure crop

Universität Rostock
Traditio et Innovatio

JKI Julius Kühn-Institut

Cattle manure, Horticulture compost

Universität Rostock
Traditio et Innovatio

JKI Julius Kühn-Institut

Cattle manure, Horticulture compost

Soil characteristics, field experiment

Treatment	OM_t %	DHA[1)] µg TPF g^{-1}	Pw mg 100 g^{-1}	Pdl mg 100 g^{-1}	Pox mmol kg^{-1}	PSC mmol kg^{-1}	DPS %	Maize yield 2008 DM, dt ha^{-1}
Without fertilizer	2.22	47.6	0.78	3.20	12.0	30.0	39.5	136
TSP autumn	2.35		1.34	4.85	13.4	30.2	44.8	140
TSP spring	2.37		1.33	4.90	13.9	29.2	45.8	135
CM	2.54	93.3	1.39	4.91	14.2	30.0	45.8	148
BC	2.64	93.9	1.48	5.07	14.2	30.0	47.0	153
CM x TSP autumn	2.55		1.66	5.81	14.7	30.1	47.9	148
CM x TSP spring	2.55		1.57	5.85	14.4	29.7	48.0	152
BC x TSP autumn	2.65		1.71	5.97	14.9	30.3	49.0	158
BC x TSP spring	2.67		1.80	6.12	15.0	28.1	50.9	162
LSD (0.05)	0.19	30.9	0.15	0.29	0.68	n.s.	2.54	11.0

[1)] DHA only determined for treatment without fertilizer, CM, and BC in 2004

Soil parameters - autumn 2007, after 9 year experimental time

Universität Rostock Traditio et Innovatio

Julius Kühn-Institut

- ✓A balanced P fertilization should avoid P dumping & P mining.
- ✓The importance of residues as a source of phosphorus increased.
- ✓100% availability of P in organic fertilizers can be assumed on long-term basis.
- ✓Ashes are an important nutrient source and may have a good P fertilizing effect.
- ✓P utilization depends also on the cultivated crops and on soil parameters.
- ✓Possible risks have to be considered with respect to soil and water protection and food chain

Thank you for your attention

The projects were supported by DFG, BMELV, K+S Kali GmbH

Universität Rostock Traditio et Innovatio

... leaves behind hard evidence

The production of each ton of phosphoric acid generates 5 tons of phosphogypsum.

About 60% of the total P load to waterbodies in Germany are non-point losses with agriculture being the greatest contributor with 90%.

Waterbodies are sensitive against high P loads because of a limited buffer capacity. Excessive algae growth causes eutrophication and cyanobacteria (blue-green algae) are a serious threat to human health.

P fertilization is essential to satisfy the nutrient demand and warrant soil fertility. But excessive P applications enhance the risk of P losses to waterbodies by run-off and erosion.

Mineral P fertilizers add significant amounts of U to soils.

Sewage sludge

In 2006, wastewater treatment plants recovered 50,520 t P equaling $2{,}06 \cdot 10^6$ t (d.w.) of sewage sludge in Germany. 30% of the sewage sludge was applied on agricultural land (BMU 2007).

In 2007, ~50% of all sewage sludge was incinerated in Germany (UBA 2008); the capacity for mono-incineration is expected to stagnate at $550 \cdot 10^3$ t (d.w.) yr^{-1}. The proportion of co-incineration in coal-fired power plants, refuse incinerators and cement works are expected to increase significantly.

Meat bone meal

Elements of sewage sludge, MBM and their ash products (Rosyadi 2003)

Waste product	C	N	P_{total}	$P_{citric\ acid}$	K	Ca	Mg
	(%)						
MBM	40	7.7	4.4	3.1	1.9	7.7	0.25
MBM ash	**0.1**	**0.01**	**18.6**	**7.0**	**0.4**	**34**	**0.93**
Sewage sludge	26	3,0	1.2	1.2	0.8	12.5	0.60
Sewage sludge ash	**0.4**	**0.00**	**3.6**	**2.0**	**0.3**	**43**	**1.07**

Incineration of MBM destroys pathogens and preserves P!

Animal carcass incinerator

(Defra 2008)

Microbial activity in soil

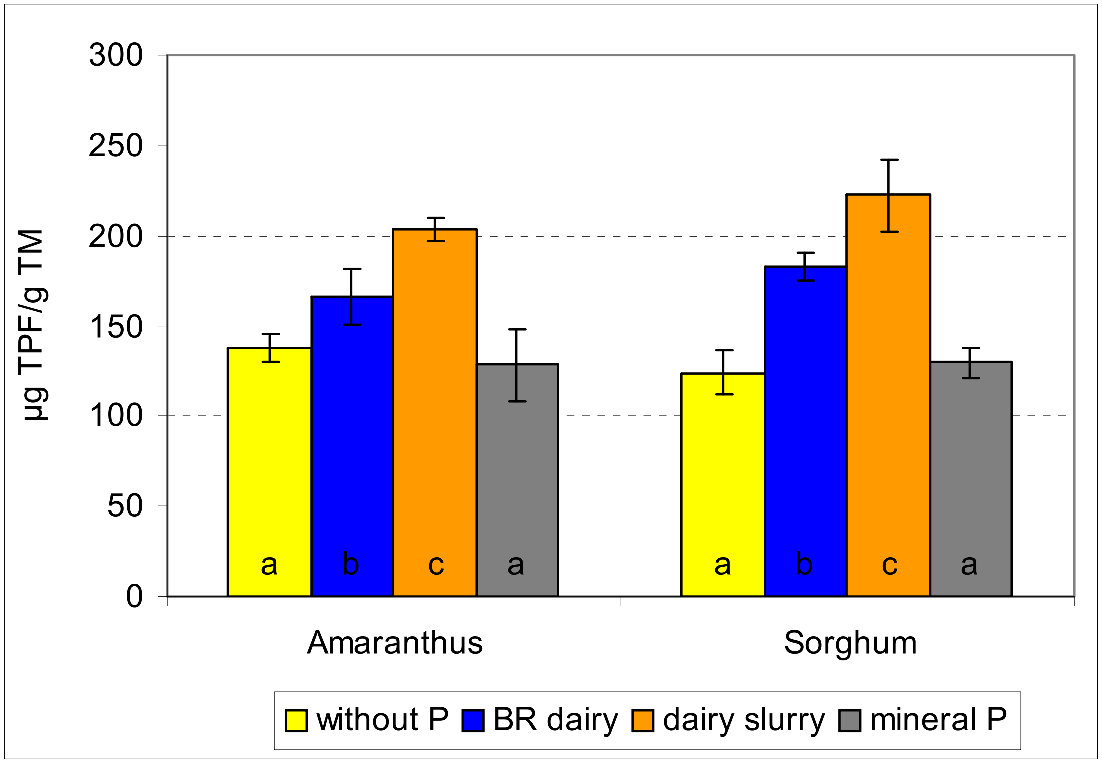


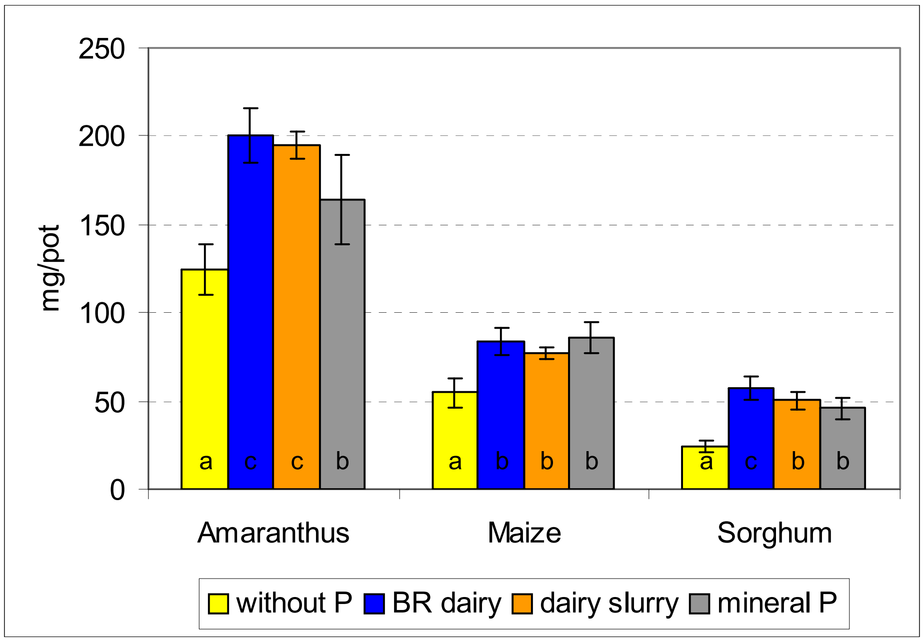
Figure 3: Effect of fermented and unfermentd dairy slurry on microbial activity iin the soil (Dehydrogenase-activity, after 24 h, incubation at 37 °C) (Duncan Test, α=0,05)

Universität Rostock
Traditio et Innovatio

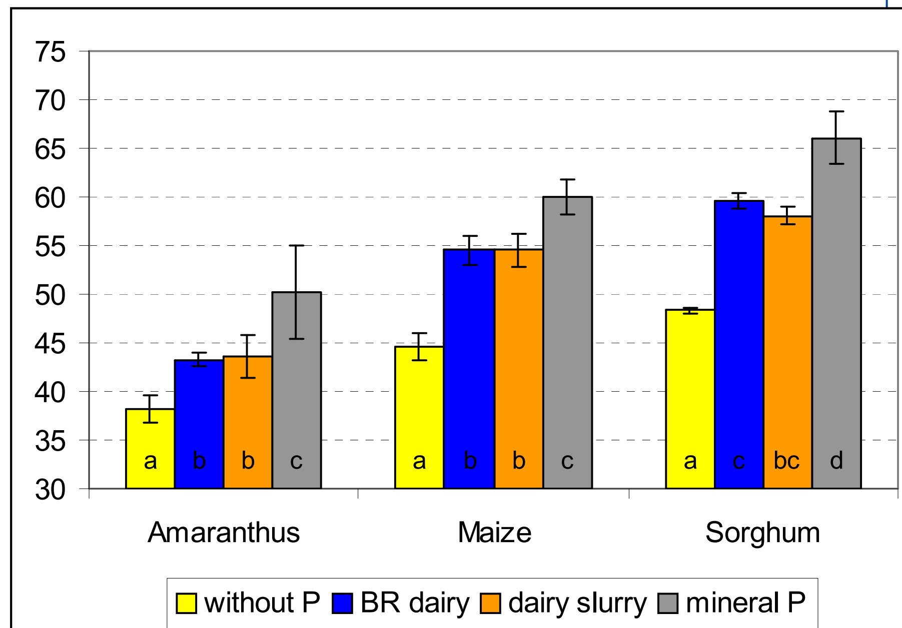
JKI Julius Kühn-Institut

Biogas slurry

Crop P uptake



P-DL content in soil



pot experiment , 6 kg of soil, (Duncan test; α=0,05)

The microbial activity and activities of enzymes in soil were lower for the digested dairy slurry (less degradeable org. compounds)