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Phosphorus budgets and bioavailable phosphorus content in soil - results of a long-term field experiment

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Due to the scarcity of mineable phosphorus (P) an efficient use of P is a main objective in sustainable agriculture. An application of P adapted to crop requirements and the nutrient recycling with wastes and residues can help to achieve this aim. The content of bioavailable P in soil can be used to evaluate the current soil P status and to calculate the fertilizer need. However, the availability of P in soil depends not only on the P input but is also regulated by biological and biochemical processes in soil and environmental conditions. Long-term field experiments can give an extensive overview about the effectiveness of P application also considering the influence of annual environmental conditions, P mobilization and translocation processes in soil. At the Rostock long-term field experiment the effect of single and combined P treatments are investigated since 1998.

The long-term field experiment is located in the northeast of Germany and influenced by a maritime climate (600 mm annual rainfall; 8.1°C annual temperature). The initial double-lactate soluble P content (Pdl) of the soil was 42.2 mg kg^{-1} indicating a sub-optimal P supply according to the German soil P test classification. The trial was designed as a randomized split plot experiment in four replicates. The main plots comprised three organic P treatments (no P, biowaste compost, and cattle manure). The subplots comprised three inorganic P treatments (no P, Triple-super-P (TSP), and biomass ash). Compost and manure were applied at rates of about 30 t ha^{-1} in September every three years beginning in 1998. TSP and biomass ash were applied annually at rates of 21.8 to 30.0 kg P ha^{-1}. Soil and plant sampling was done twice a year and a broad spectrum of soil characteristics, crop yields and crop P uptakes were investigated.

The different P treatments and their combinations resulted in different crop P uptakes and P budgets (Table 1). These management effects also influenced the bioavailable P contents in soil (measured as Pdl; Table 2). Highest contents of Pdl were measured in the combined fertilizer treatments with compost and inorganic fertilizers (about 55 mg kg^{-1} soil). Compost application resulted in higher Pdl contents than manure application, which could be explained by the relatively high percentage of mineralized P in compost and its stable organic compounds. The organic fertilizers had a comparable P fertilizer effect as the inorganic fertilizers. Close significant ($p<0.05$) correlations between the P budgets and the Pdl concentrations in soil in the particular periods were calculated ranging from 0.73 to 0.98. However, the data also showed fluctuations of the Pdl values during the experimental period, which cannot be explained only by the P supply. Here, we expect a decisive role of biological and chemical P turnover processes which may be affected by weather conditions. It can be concluded that P budgets can be used to predict changes in soil test P over long periods under field conditions but may be unsuitable to reflect the current soil P status.

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Table 1. Total P supply, total crop P uptake (P removal) and total P budget accumulated after 17 years in field experiment Rostock

Treatment	Total P supply	P removal (kg ha^{-1})	P budget
Control	0	422	-422
TSP	379	467	-88
Ash	348	439	-91
Manure	391	465	-74
Man + TSP	770	467	303
Man + Ash	739	482	257
Compost	396	470	-74
Com + TSP	775	498	277
Com + Ash	744	508	236

TSP = Triple-Superphosphate, Manure/Man = Cattle manure,
Compost/Com = Biowaste compost, Ash = Biomass ash

Table 2. Contents of bioavailable P (Pdl, mg kg^{-1} soil) as average of three-year periods and over the whole experimental time from 1998 to 2015 in the Rostock field experiment

Treatment	1998-2000	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015	Mean
Control	35.7a	41.1a	36.6a	32.3a	30.4a	28.8a	34.a
TSP	41.7bc	51.4cd	48.1c	40.1b	38.8b	36.7b	43.8c
Ash	36.1a	46.7b	44.6b	41.4b	37.0b	36.8b	41.b
Manure	40.7b	50.0c	48.9cd	40.5b	37.1b	37.4b	43.5c
Man + TSP	42.2bc	58.7e	54.2f	47.2c	44.6d	44.6d	49.e
Man + Ash	46.8de	51.8cd	51.8ef	44.8c	41.7c	43.3cd	47.d
Compost	44.3cd	53.1d	51.1de	46.8c	45.2d	41.2c	47.d
Com + TSP	48.0e	58.8e	61.1g	54.9d	53.2e	49.5e	55.3f
Com + Ash	51.2f	59.3e	60.3g	54.6d	51.3e	49.2e	55.2f
Mean	43.0	52.3	50.8	44.7	42.1	40.8	

Different letters indicate significant different means between fertilizer treatments, Duncan-test P ≤ 0.05; TSP = Triple-Superphosphate, Manure/Man = Cattle manure, Compost/Com = Biowaste compost, Ash = Biomass ash, each period consists of three single years, soil sampling was done every single year