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Evaluation of Potassium from Plant Residues in Arable Cropping Systems

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Summary

In one model experiment and four long-term field trials the effects of straw, beet tops and stable manure on removals of K by plants and on K contents of soils were examined. In principle, K supplied by crop residues is adequately determined by conventional extraction methods (model trial). Utilization by plants varied according to K supply of the soil and amount of fertilizer K application between 10 and 90%. Positive balances of K (fertilizer added – removed) after organic manuring were expressed in an increase of the K pool in the soil (partly CAL-K, but especially HCl-K); on soils with a good buffer capacity for K, CAL-extraction did not indicate positive K balances sufficiently.

Crop residues, as is known, contain much potassium *(e.g.* straw 45-55 kg K, 40 t beet leaves 200-250 kg K). Consequently, the actual amount of K removed by a crop depends largely on whether or not the residues are removed from the field.
In summary, K fertilizer policy in the Federal Republic of Germany is related to soil tests as under.

K supply according to soil test:	K application:	
low	removal + addition	optimally
medium – high	removal	distributed
very high	removal — reduction	within a crop sequence

Potassium contained in crop residues or supplied by farm manure is equivalent to that in fertilizer.

Pot trials have shown that potassium in plant residues has the same good effect as mineral potassium *(e.g. Kuhlmann [1983]; Amberger et al. [1984]* for slurry manure). *Von Braunschweig [1985]* however found fertilizer K to be more efficient in field trials than potassium in straw or beet tops.

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Practical experience shows that a positive K balance (application – removal), especially as a consequence of organic manuring, is often not reflected in measurements of available potassium in the soil. This is partly explained by the fact that especially in well buffered soils potassium measured by conventional methods (DL, CAL, $CaCl_2$ etc.) is not an adequate value for balance accounting *(Amberger* and *Gutser [1976])*. In the work described we have tried to elucidate the potassium effect of crop residues. However, as these experiments were concerned with various problems and as potassium supplied by crop residues was only an addition to, but did not substitute, fertilizer K, optimal supply to plants was in most cases already guaranteed by fertilizers, and the potassium in crop residues could not effect any yield increases and at most led to higher removals of K by the plants.

1. Pot experiment on the evaluation of potassium from crop residues in the soil

In a model trial we tried to clarify how far potassium supplied by crop residues and slurry can be estimated by conventional soil testing methods.

Experimental outline

soils: a) loamy sand (12% clay, 19% silt), pH 6.0, CAL-K: 30 mg/100 g soil
b) silty loam (22% clay, 65% silt), pH 6.2 CAL-K: 26 mg/100 g soil)
500 g/pot

incubation: 2, 8 and 18 weeks (18 °C, 60% of max. water capacity)
organic manure (mixed with soil):

		K supply (mg total K 100 g soil)	CAL soluble portion %
1. control		—	—
2. wheat straw	2 g DM/pot	8.4	73
3. beet leaves	0.5-1 cm chopped	12.9	73
4. green rape	— fresh material —	12.2	73
5. cattle slurry (10g/pot)		7.6	96
6. KCl (in solution)		8.3	100

From73 up to almost 100% (slurry) of the potassium contained in organic manure was CAL soluble.

Results

Potassium in crop residues and slurry was recorded properly by CAL – and $CaCl_2$ – extraction independent of soil or incubation time; it did not differ essentially from potassium applied in mineral form (Table 1).

Table 1 Recovery of K added in form of plant residues (% of total K applied – minus control)

	Loamy sand			Silty loam		
Manuring	2	8	18 Wo	2	8	18 Wo
			CAL-extraction			
straw	73	82	87	73	68	67
beet tops	83	104	99	88	88	84
green rape	92	102	104	97	99	83
slurry (cattle)	79	93	99	84	80	85
KCl	112	84	80	55	65	71
			$CaCl_2$-extraction			
straw	60	60	58	47	46	43
beet tops	73	85	71	57	60	53
green rape	66	82	83	72	66	65
slurry (cattle)	70	74	80	68	53	51
KCl	67	71	74	57	49	43
			Changes in control (mg K/100 g soil)			
extraction						
CAL:	31	31	29	26	28	26
$CaCl_2$:	19	19	17	14	14	13

Potassium from beet leaves and green rape (higher amounts of applied K) as well as slurry K appeared faster and more complete in the soil extract than potassium contained in straw. CAL dissolved more K than $CaCl_2$ (higher exchange capacity). In most cases on the loess soil the recovery of added potassium decreased in most cases with increasing incubation time ($CaCl_2$), in some cases it did not change (CAL) with the exception of CAL-extraction after KCl – application.

2. Field trials with straw and stable manure

In several long-term field trials (fertilizer tests with various P and K forms or increasing N application), the nutrient and special additional effects of organic manure were studied on plots receiving straw and stable manure *(Amberger* and *Gutser [1976]; Gutser* and *Amberger [1985]; Bosch* and *Gutser [1985])*.
Site conditions:

Weihenstephan — 810 mm precipitation
7.7 °C mean annual temperature
brown earth from loess loam
22% clay — C_t = 1. 1%
60% silt — N_t = 0.12%
Total K: 1.5% — CEC = 14 me/100 g

Experiment 1: **Increasing N at uniform K fertilizer application with and without straw**

duration: 1968-1981

improved three-year rotation: In 2 years out of 3 there was straw application with compensating N dressing and a mean K supply of 28 kg K/ha yr
mineral K application: 135 kg K/ha yr
initial soil K: 7 mg DL-K/100 g soil.

Results

Straw manuring had no effect on crop yields and only slightly increased K removals (Table 2). The resulting K balance was raised by straw application from +35 to +60 kg/ha as mean of all years. Utilization of potassium supplied with straw (additional removal as percent of added amount) was 11%.
Corresponding with positive K balance, DL-soluble potassium was raised by fertilizer application from 7 to 13 mg/100 g soil; additional straw manuring gave only a further slight increase of K content of the topsoil. Somewhat more distinct was an increase of K extractable by HCl even though this increase did not nearly reflect the positive balance of altogether 350 kg/ha caused by straw.

Table 2 Manuring of straw in combination with fertilizer NPK application (1968-81)

Straw	Yield t DM/ha yr	Removal kg K/ha yr	Balance of K (kg/ha yr) fert. applied-removal	Utilization of straw-K (%)
—	7.5	100	+ 35	—
+	7.5	103	+ 60	11

Soil analysis (mg K/100 g soil)

	topsoil				subsoil	
		DL		HCl	DL	HCl
straw	1963	1976	1984	1984	1985	1985
—	7	10	13	67	5	51
+	7	12	14	71	5	51

Experiment 2: **Effect of straw manuring with and without additional mineral fertilizer application (NK) – test with various P fertilizers**

duration: 1959-1984

crop rotation, every second year straw manure with an average K supply of 18 kg/ha yr

mineral K application: 0 and 120 kg K/ha yr
initial K supply of the soil: 9 resp. 17 mg DL-K/100 g soil

Results

Straw manuring resulted in a distinct increase of yields and K removals by the crops especially in plots without mineral fertilizers (Table 3).

Table 3 Effect of manuring with straw with and without mineral fertilizer (1959-84)

		without mineral fert.		NK fertilizing	
	straw	—	+	—	+
yield (t DM/ha yr)		3.3	4.5	8.2	9.0
removal of K (kg/ha yr)		39	55	103	112
balance of K (kg/ha yr) fert. applied-removal		— 39	— 37	+ 17	+ 26
utilization of straw-K (%)		—	89	—	50
Soil analysis (mg K/100 g soil)					
DL	1954	9	9	17	17
	1971	8	8	14	15
	1981	8	8	13	16
	1984	8	10	17	20
	subsoil:				
	1974	7	7	7	7
	1985	7	7	7	7
HCl	1981	59	60	68	75
	1984	60	62	75	79
	subsoil				
	1974	52	49	55	55
	1985	55	51	55	55

For potassium supplied by straw, the calculated utilization is 89 (no fertilizer applied) and 50% (with K fertilizer).

In spite of a negative K balance on plots without mineral fertilizers, DL-soluble K (8 mg/100 g soil) remained practically on the initial level; straw caused a small increase especially of non-exchangeable potassium. Likewise, a positive K balance on plots with PK-application did not essentially change the DL-soluble K. Straw manuring is expressed in an increase of DL- as well as HCl-extractable K of the soil. In this long-term trial, an agreement between the amount of K supplied by straw and the additional removal by plants as well as the amount of K left in the soil was found at least by way of calculation. The low sensivity of the CAL-extraction to positive or negative balances indicates a high buffering capacity for K in this loess soil.

Experiment 3: **With the same site conditions, the K-effect of stable manure was calculated**

duration: 1942-1973

improved three year-rotation: normally every third year 30 t stable manure/ha to leaf crops equivalent to 51 kg K/ha yr

uniform NP-fertilizer
K-rates: 0 or 100 kg K/ha yr

Results

Stable manure with or without additional K fertilizer caused a marked increase in yields and K removals (Table 4). In plots with NPK, the K balance was always negative, with mineral K or stable manure, however, near to zero.

Table 4 K-effect of stable manure (1942-73)

		NPK_0		NPK_{100}	
		stable manure			
		–	+	–	+
yield (t DM/ha yr)		7.2	9.0	9.3	10.1
removal of K (kg/ha yr)		69	95	127	144
balance of K (kg/ha yr)		– 69	– 44	– 27	+ 7
fert. applied-removal					
utilization %:					
mineral K		–	–	58	49
K in manure		–	49	–	33
both		–	–	–	50
	1975:	Soil analysis (mg K/100 g soil)			
DL	(0-25 cm)	6	7	7	9
HCl	(0-15 cm)	31	33	36	40
	(30-45 cm)	31	31	28	34
K-fix.*	(0-15 cm)	22	21	4	1
	(30-45 cm)	23	24	20	22

* wet fixation

Utilization of manure-K was somewhat lower than of mineral K, especially when stable manure was applied in addition to mineral K fertilizer; overall utilization of applied K was 50%. The slightly positive K balance with stable manure when added to mineral K is demonstrated in somewhat higher values for DL-, and especially in HCl-soluble K (0-45 cm soil layer); the soil did not show any fixation of K.

No complete record of the fate of K from stable manure can be given from the crop results and soil analysis, but, considering the differing application times (periodic application of stable manure), it can be concluded that the two K forms had virtually identical effects.

3. Field trial with beet tops

Since 1976, an experiment has been run in Weihenstephan with varying levels of K-application to sugar beet as single crop on a humic limy gley soil (25 cm humic layer on top of a 50 cm river marl layer). Since 1978 this trial has been supplemented with plots receiving an additional application of beet tops.

soil: pH 7.3 — 20% clay — C_t = 3%
free $CaCO_3$ = 50 – 70% — 30% silt — N_t = 0.36%
wet fixation of K: 35 – 45 mg K/100 g soil — CEC = 25 me/100 g
duration: 1978-1985
optimized NP fertilizing
K application: 125, 250 and 375 kg K/ha yr
initial K supply of the soil: 1-3 mg K/100 g soil

Results

Increasing rates of K up to K_{250} increased yields significantly, K_{375} only raised K contents of plants, but resulted in a positive K balance (Table 5).

Table 5 Manuring with beet tops in single cropping of sugar beet (1978-85)

K-fertilizer		K_0	K_{125}		K_{250}		K_{375}	
beet leaves		–	–	+	–	+	–	+
yield (t DM/ha yr)		11.9	19.8	20.4	21.9	20.3	21.7	21.2
removal of K (kg/ha yr)		115	202	232	270	288	315	309
balance of K (kg/ha yr) fert. applied-removal		– 115	– 80	+ 12	– 26	+ 120	+ 51	+ 225
utilization (%):								
mineral K		–	70	–	62	–	53	–
K in leaves		–	–	25	–	11	–	0
both		–	–	47	–	42	–	36
		soil analysis (topsoil)			(mg K/100 g soil)			
CAL	1977	1	1	1	1	2	3	4
	1982	1	2	3	3	6	4	8
	1985	3	3	3	3	8	5	11
$CaCl_2$	1985	0.6	0.7	0.9	1.2	3.2	2.1	5.5
K-fix.	1979	49	48	46	43	37	32	32
	1982	36	37	26	34	29	26	21
	1985	47	44	36	33	26	26	24

Beet leaves applied in addition to fertilizer gave only slightly increased yields on the level K_{125}, in combination with K_{250} only higher K removals of crops. K balances at the levels K_{250} and K_{375} were highly positive (+ 120 and 225 kg K/ha yr).

Utilization of fertilizer K attained high values (70% at K_{125} and 53% at K_{375}), at best only 25% K from beet tops applied in addition to fertilizer was utilized (K_{125}). When considering the amounts of K applied with beet tops, the calculated utilization of K for the combination K_{125} + tops (247 kg K/ha/yr added) was higher (47%), but still lower than for fertilizer K (62% at K_{250}). The positive K balance of the levels K_{250} and K_{375} plus beet leaves is expressed in a marked increase of CAL-K; correspondingly, K-fixation was generally lower after organic manuring. On the whole changes in the soil K are not sufficient to account for the positive K balance.

4. Discussion of results

From consideration of the results of these 4 long-term field trials, the conclusive evaluation of the effects of K in crop residues, is not possible since in some cases there were evident discrepancies between positive K balances in crop trials and increases of K contents in soils. In all trials where K need of crops was guaranteed by fertilizers allone, utilization of K from crop residues was only 10% or less.

Contrarily, in trials without additional fertilizer application, K in residues was utilized to the extent of 50 up to 90%; effects of K from straw were largely identical with stable manure.

In the trials with stable manure on loess brown earth soils and with beet tops on the humic limy gley soil, potassium supplied by the organic manure was not utilized quite as well as fertilizer potassium (see below). In general (except experiment 1: straw manuring on brown earth with optimized K application), low utilization of potassium in crop residues resulted in a distinct increase of K-contents in the soil, especially of less exchangeable forms (HCl-K) and in a decrease of wet fixation. Neither $CaCl_2$ – or CAL-extraction are suitable for K balance accounting on well buffered soils even though mineral and organic fertilizers are recorded equally well as is shown in the pot trial. This low sensitivity of the CAL or $CaCl_2$ method on soils with high buffer capacity consequently proves a great handicap to the evaluation of fertilizer demands (see introduction); the desired control function of soil analysis for proper fertilizing is questionable in such cases.

We cannot explain why in one of the long-term field trials K from straw manure was neither appreciably utilized nor did it increase the soil potassium; leaching or fixation is not possible on this site.

The results on limy gley soil have to be interpreted somewhat differently: the slightly smaller effect of K in beet tops as compared to fertilizers might be caused mainly by different application times (tops in autumn, fertilizer at sowing). The following explanation is suggested.

1. Leaching of K from tops during non-growing season (shallow humic soil with high lime saturation),
2. stronger fixation of beet leaf-K since it was applied about 6 months before needed by plants (soil with an intermediate fixation potential).

A heterogeneous mixing of organic manure and therefore uneven distribution in the soil should not have any effects on the efficiency of K in long-term trials.

Considering all results and making certain restrictions, the following assessment may be concluded:

1. Potassium from crop residues gives a similarly good effect as mineral potassium (utilization by plants, increase of K pool in the soil)
2. On strongly fixing soils as well as on sites with appreciable K leaching (sands and shallow humic soils, some with high lime content, K application directly at sowing often gives better effects than organic manure-K already applied in autumn.

These findings should be considered in the determination of fertilizer requirements for the respective sites.

5. References

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