


**# 9 | NOVEMBER 2025**

# Pharmaceutical residues in soil and plants

## – Results from pot tests in Umeå and Vaasa

**The use of sewage sludge in agriculture has raised concerns about pharmaceutical residues being taken up by crops and their potential effects on the environment and consumer health. To investigate this, two pot experiments were carried out during 2023–2025 in Umeå and Vaasa. The study examined the presence, degradation, and potential uptake of pharmaceuticals in soil–sludge mixtures in a northern climate. Barley and timothy were grown in pots, some of which were spiked with low concentrations of common pharmaceuticals. Pharmaceutical levels were analysed regularly at a commercial laboratory to show how these substances break down and spread in the environment. The results show that some pharmaceuticals are taken up by plants, but the risk of them entering the food chain is very low.**

### The Path of Pharmaceuticals into Nature

Pharmaceuticals are chemicals that affect biological processes. They impact not only humans and animals but also the environment. To be effective, these chemicals must be stable, which means they are not always fully broken down in the body. As a result, pharmaceutical residues can end up in urine and feces and enter wastewater treatment plants, either as unchanged substances or as degradation products.



Common pharmaceuticals were added to the pots.

The main sources of pharmaceuticals in wastewater are households, hospitals, healthcare facilities, and the pharmaceutical industry. Some substances are broken down during treatment, but many remain and spread via water or sludge. Over the past ten years, hundreds of pharmaceuticals have been detected in the environment. Concentrations in treated water are usually low, but can be much higher in sludge. How much is degraded depends on the drug's properties, sludge composition, and treatment plant design. Studies also show that pharmaceuticals behave differently during sludge post-treatment (e.g., anaerobic digestion). These factors make it difficult to predict their environmental impact.

### About the Pot Experiments

The pot experiments were conducted to study the presence and degradation of common pharmaceuticals in agricultural soil, as well as their uptake by crops. The experiments were carried out outdoors during 2023–2025. In Umeå, 10-liter buckets were used, while in Vaasa, 3-liter pots were used. In both experiments, local agricultural soil was mixed with digestate from sewage sludge as fertilizer, sourced from Vakin Ab in Umeå and Ab Stormossen Oy in Vaasa. The soil type was coarse moraine (pH 5.9) in Umeå and silty clay (pH 5.3) in Vaasa.

The experiments started in May in Vaasa and in June in Umeå. To the existing soil–digestate mixture, a blend of 7–8 commonly used pharmaceuticals was added. Bisoprolol was added only in the Vaasa experiment but was found in the digestate from both countries. The pharmaceuticals were added as a solution to the soil and mixed thoroughly. The final concentration of pharmaceuticals added was 0.031 mg per kg of dry soil.



Small glass vials with pre-mixed stock solutions of pharmaceuticals.

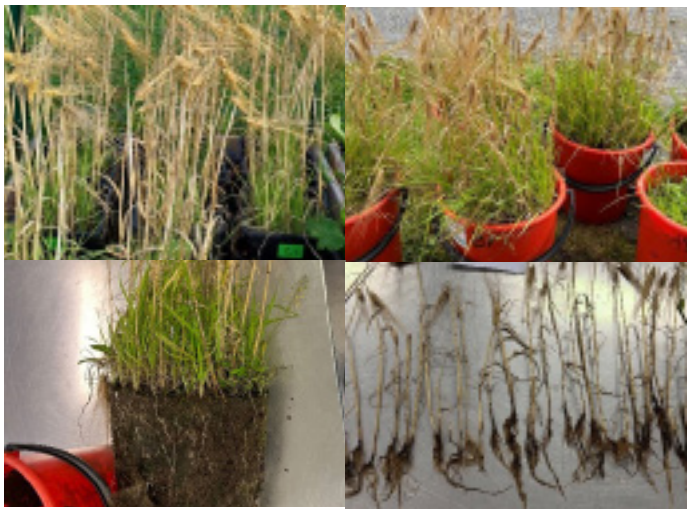
## Pharmaceuticals used

Eight commonly used pharmaceuticals:

**Bisoprolol** (beta-blocker)
**Citalopram** (antidepressant)
**Diklofenac** (painkiller)
**Ibuprofen** (painkiller)
**Carbamazepine** (epilepsy)
**Metoprolol** (beta-blocker)
**Tetracyclin** (antibiotic)
**Sertraline** (antidepressant)

## Sampling & Analysis

Barley and timothy were grown in pots divided into three treatment groups: A – added pharmaceuticals, no crop; B – added pharmaceuticals with crop; and C – no added pharmaceuticals, with crop. Initial soil and digestate samples were collected in 2023, and sampling followed the crops throughout the growing season. Barley was harvested in August/September 2023, and timothy in summer 2024, with samples collected from roots, shoots, and soil. The final soil sampling in Vaasa was conducted in April 2025 after the thaw.



Pot experiments in Vaasa and Umeå with barley and timothy. Bottom left: barley at harvest. Right: barley plants before separation of parts.

Pharmaceutical concentrations in soil and plant parts were analysed at the IVL Swedish Environmental Research Institute using LC-MS/MS, capable of detecting very low levels. Concentrations are reported in nanograms per gram (ng/g) dry weight, with all water removed to allow fair comparison between materials. Baseline soil samples collected at the start of the experiments in 2023 were analysed by Hortilab Oy Ab. Initially, pots were fertilized only with sludge-based digestate, at an amount corresponding to the maximum permitted application every five years based on phosphorus content. During the 2024 growing season, fertilization was supplemented with ammonium sulfate in May and June, corresponding to 80 kg N/ha per application.

## Our Results

Some pharmaceuticals were detected in both roots and other plant parts. In pots with added pharmaceuticals, carbamazepine, citalopram, and sertraline were found in the roots of barley and timothy. Surprisingly, traces of citalopram and sertraline were also present in control pots, likely because they were already in the digestate used as fertilizer.

In barley straw from pots with added pharmaceuticals, carbamazepine was detected, and ibuprofen was also found in straw from Vaasa. No pharmaceuticals were detected in the grains themselves from either Umeå or Vaasa. Timothy showed clear uptake of carbamazepine in the stems. In Vaasa, concentrations were 27–32 ng/g at the first harvest and 5–10 ng/g at the second harvest one month later, with similar levels in the roots. In Umeå, concentrations were higher: 170 ng/g in June and 46 ng/g in July.

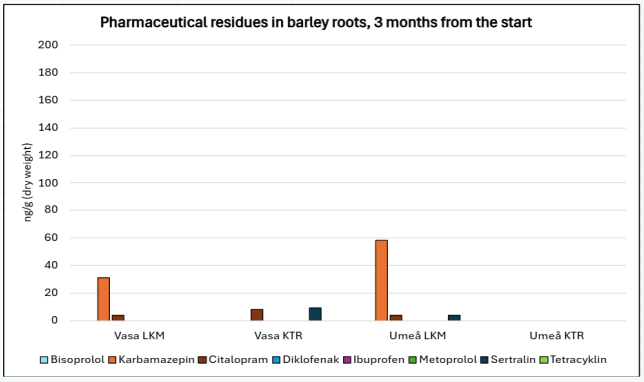



Figure 1: Presence of pharmaceuticals in barley roots three months after the start. LKM = added pharmaceuticals, KTR = control without added pharmaceuticals. Both pots fertilized with sludge digestate.

In soil with only digestate, no or very small amounts were detected. In pots with added pharmaceuticals, five substances—bisoprolol, carbamazepine, citalopram, sertraline, and tetracycline—were found three months after application. After more than a year, traces of carbamazepine, citalopram, sertraline, and occasionally ibuprofen remained. About two years later, carbamazepine, citalopram, and sertraline were still present in the treated soil.

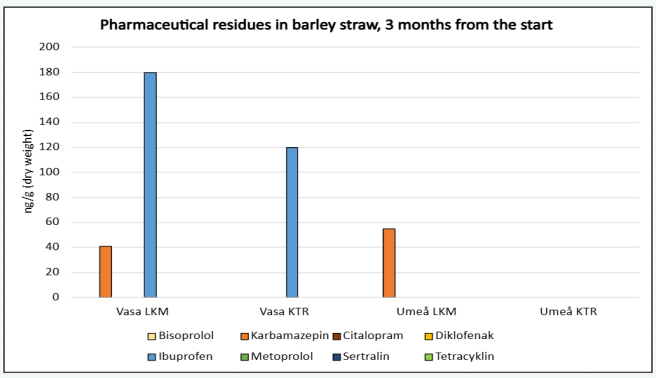



Figure 2: Barley straw treated with pharmaceuticals three months after the start. Ibuprofen was briefly detected in the control but was negative in a repeat analysis four months later.

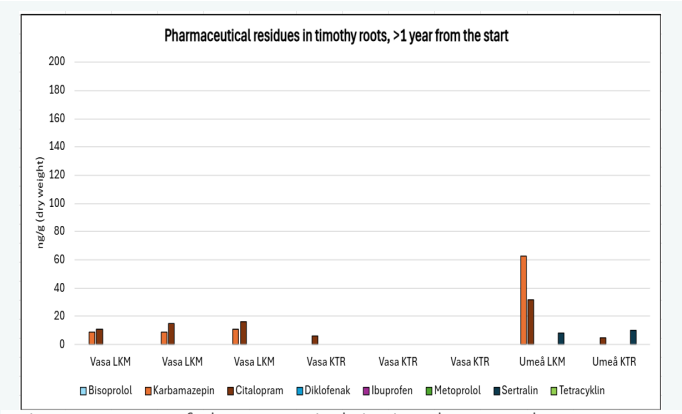



Figure 3: Traces of pharmaceuticals in timothy roots about one year after the start. Vaasa samples were analysed individually, Umeå samples were pooled by treatment.

Two years after the start, bisoprolol unexpectedly reappeared in soil from pots without crops. The substance had not been detected after one year but was present at the start and after three months. In contrast, no pharmaceuticals were detected in control soils without added substances after two years. Carbamazepine, citalopram, and sertraline were found in both roots and plant parts such as timothy stems and barley straw, with particularly high carbamazepine uptake in timothy, higher in Umeå than in Vaasa.

Carbamazepine is persistent in the environment and has previously been reported in plants such as radish, ryegrass, lettuce, spinach, cucumber, and pepper. Citalopram and sertraline are antidepressants of concern due to potential negative effects on aquatic organisms. Their uptake in plants is less studied, but citalopram has been shown to be taken up by roots of onion, radish, and spinach. Some pharmaceuticals, especially carbamazepine, citalopram, and sertraline, remained in the soil almost two years after application, demonstrating slow degradation.

Bisoprolol and ibuprofen showed inconsistent patterns over time, possibly due to uneven sample mixing, making the results somewhat uncertain. Tetracycline was detected only early in soil samples, suggesting rapid leaching or degradation, despite its usual strong binding to soil, particularly at low pH. Diclofenac and metoprolol were not found in either soil or plant samples, as expected. Diclofenac degrades quickly in soil, even though it may persist in wastewater, while metoprolol can remain longer but is considered to have a low risk of accumulating in plants or animals.

## Conclusions

The results show that some pharmaceuticals can be taken up by plants and remain throughout the growing season. The most important finding, however, is that no pharmaceuticals were detected in the barley grains—the part consumed by humans. Transfer to animals via feed, and further into milk and meat, is less studied but appears to occur in very small amounts. Therefore, the risk of pharmaceuticals entering the food chain is low, even if they persist in the environment.

Soil that received only digestate, without added pharmaceuticals, contained very small or no traces of the substances studied. This suggests that sludge is not always a major source of pharmaceutical residues in agricultural soil at realistic application rates and that the sludge did not contain unusually high levels initially.

Nevertheless, our results raise questions about how pharmaceutical residues spread in the environment and affect ecosystems and food production. More research is needed to understand how these substances degrade in soil under Nordic climatic conditions to reduce environmental impact.



Krukförsök i 10-litershinkar i Umeå med korn och timotej. Inga läkemedel återfanns i de delar människor äter.

## Read more

Previously published material on pharmaceuticals in digestate through the Botnia Näring i Kretslopp project:

Infoblad, Reduktion av läkemedel under rötning

Rapport, Reduktion av läkemedel under anaerob rötning

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