

Weed Seed Survival in Anaerobic Digesters

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MANURE IS AN IMPORTANT SOIL AMENDMENT PROVIDING valuable nutrients. However, many assume manure is always rich in weed seeds. The opposite is probably the case as most of our harvested forage is relatively free of weed seeds. Exceptions obviously exist. There is no simple method to extract weed seeds from feed or manure and to then test them for viability. So the best advice is to understand current knowledge about weed seeds in manure and how they may impact your operation. Key factors that determine the potential for weed seed problems from livestock systems are feed sources, type of animals, and type of feed and manure handling systems.

Feed Sources

Weed seeds enter livestock systems from forages, grain, and palletized feed products. Cash *et al.* (1998) estimated that for palletized products, less than 1% of weed seed survive feed grinding and palletizing. Though small in number, feed pellets can be a source of introduction of new weed species to a farm, and if one considers the volume of palletized feed fed, can be a significant source of weed seed. The biggest contribution of weed seed can come from contaminated hay and grain, however. A portion of weed seed present in feed can remain viable after passing through an animal's digestive tract. Weed seed present in bedding or in spilt-feed bypasses the animal directly entering the manure stream. Both of these weed seed sources may result in manure containing viable weed seeds. A study conducted in New York State (Mt. Pleasant and Schlather 1994) showed that farms with low amounts of weed seed in dairy manure used feed with low numbers of weed seeds. Farms with high manure weed seed counts either harvested feed from weedy fields or imported feed containing weed seeds. A California study (Cudney *et al.* 1992) showed that dairy manure from producing cows had fewer weed seeds than manure from dry cows,

presumably because the dry cows received lower quality (weedier) feed.

Type of Animals, Ensiling, Digestion, and Manure Handling

The animal source of manure can be important. Two studies in Nebraska characterized the effects of the digestive tract and manure on weed seeds (Harmon and Keim 1934). Weed seeds were fed to calves, horses, sheep, hogs, or chickens. Nearly 25% of the seeds fed to hogs and cattle were recovered in the manure, while only 10 to 12% were recovered from horses and sheep. Chickens were the most effective in destroying weed seeds with only 2% of the velvetleaf seeds fed recovered, while none of the bindweed, sweet clover, smooth dock, smartweed, wild rose and pepperweed seeds fed were recovered.

Of the seeds recovered from calves, horses, sheep or hogs, an average of 25% germinated. Although few in number, 62% of the velvetleaf seeds that survived the trip through a chicken germinated, suggesting that the gizzard may have actually scarified the seed and stimulated germination. Combining seed recovered and germination of weed seeds fed, sheep, horses, pigs, and calves passed 6, 9, 9, and 10% viable seeds, respectively, while poultry passed only 1%

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Table 1. Average weed seed viability after ensiling in a silo, fermentation in a rumen, or both. Lethbridge, Alberta. 1986-1989.

Species	Control	Ensiling in asilo	Rumen	Silo and rumen
	Viable seed (%)			
Green foxtail	96	0	17	0
Downy brome	98	0	0	0
Foxtail barley	87	0	0	0
Barnyardgrass	97	0	0	0
Flixweed	92	5	7	5
Kochia	94	10	15	10
Redroot pigweed	93	6	45	4
Lambsquarters	87	3	52	2
Wild buckwheat	96	30	56	16
Round-leaf mallow	93	23	57	17
Pennycress	98	10	68	10

Adapted from Blackshaw and Rode. Weed Sci. 39:104-108. 1991.

viable seed owing to the grinding action of sand in the gizzard. Olson and Wallander (2002) found that only 4% of mature leafy spurge seed was recovered when fed to sheep, and for grazing, recommended feeding livestock uninfested feed for 4 to 5 days before transfer to grazing land not infested with leafy spurge.

The fermentation process that is part of ensiling corn or forages can reduce the viability of weed seed, as can digestion in the rumen of cattle. In general, grass weed seeds are more likely to be killed by ensiling or rumen digestion than broadleaf weeds. In a study by Blackshaw and Rode (1991), seeds of downy brome, foxtail barley and barnyardgrass died if ensiled for 8 weeks or by rumen digestion for 24 hours (Table 1). Some green foxtail seed survived rumen digestion but were killed by ensiling. Broadleaf weeds are more likely to be killed by ensiling than by rumen digestion, but both processes are needed to kill the greatest number of seed. This study showed that ensiling redroot pigweed, common lambsquarters or wild buckwheat seed for 8 weeks reduced weed seed survival more than rumen digestion.

Both ensiling and rumen digestion reduced but did not eliminate the viability of flixweed, pennycress, kochia, pigweed, lambsquarters, wild buckwheat and round-leaved mallow. A few seeds remained viable in all treatments and could germinate in the field. Hard-seeded broadleaf weed seeds such as velvetleaf, field bindweed and common lambsquarters, were less likely to be killed by rumen digestion than other broadleaf seeds (Harmon and Keim 1934).

Recent research on the effects of manure handling on weed seed is limited, but earlier works add valuable insight. An early 1900 Maryland Extension Bulletin was one of the first to report the effects of animal digestion and manure handling on the vitality of weed seeds (Oswald 1908). Two sources of weed seeds in manure were studied: one was contaminated feed that passed through the animal, while the other source was seeds in the bedding which bypassed the animal. These seeds from 52 weed species were placed in piles of horse, cow, or a mixture of horse and cow manure. The temperature in the piles reached 201°F for horse manure, 168°F for cow

manure, and 188°F for the mixture. After 60 days, the temperature of the manure pile cooled to the ambient temperature so the seeds were recovered and germination tests conducted. All seeds of all 52 weed species died at these temperatures in manure piles.

Oswald (1908) also reported on seeds of 21 species that were fed to 1-year-old dairy animals, with the manure managed in ways common at the time. When manure was hauled daily to fields and shallowly mixed with soil, 13% of the fed seeds germinated. The species that survived feeding were roundleaf mallow, jimsonweed, common ragweed, wild mustard, pepperweed, smart-weed, horse nettle, cockle and dock. If fresh manure was plowed into the soil, only 3% of fed seeds germinated. In modern containment systems, sediments from either solid separators or sedimentation ponds, may concentrate the weed seed in liquid manure, creating manure with very high numbers of viable weed seeds (Cudney *et al.* 1992) compared to that observed by Oswald.

In Idaho, Atkeson and colleagues (1934) assessed the impact of cattle digestion and subsequent manure storage on the viability of weed seeds. Milk cows were fed 2 quarts of weed seeds in a single day and the manure collected, mixed with straw to simulate barn manure, and stored for 3 months. Seeds passed through the animals for 4 days. Weeds with soft seed coats were more affected than those with hard seed coats. Digestion alone reduced the viability of wild oats, yellow sweet clover, broadleaf plantain and alfalfa by more than 80%, but had considerably less impact on green foxtail, common lambsquarters, curled dock, redroot pigweed and cow cockle. Add 3 months storage in manure, and very few viable weed seeds were found. Only pigweed, curled dock, lambsquarters, and cow cockle seed

survived both digestion and manure storage. All seeds of the following species died: yellow sweet clover, buckthorn plantain, green foxtail, pennycress, dodder, wild oats, tumble mustard, and Russian thistle.

More recently, Mt. Pleasant and Schlather, (1994) collected manure from fresh droppings in the barn or from piles of manure just prior to application in the field on 20 dairy farms in upstate New York. They found apparently viable seed from 13 grass and 35 broadleaf weed species. Lambsquarters seed was in the manure of more than half the farms, yellow foxtail in 35%, common chickweed and dandelion in 30%, and wild mustard, redroot pigweed, and barnyardgrass in 25%. One farm had 400,000 seeds per ton of manure, most of which were common lambsquarters seeds. Four farms had no weed seed in the manure and the rest averaged more than 75,000 seeds per ton of manure.

Applying 30 tons per acre of manure with 75,000 seeds per ton would increase the seedbank by 2.25 million

seeds per acre. Is this a serious situation? This depends on the current number of weed seeds in the seed bank. Estimates of weed seed in trials in Wisconsin showed 15 million weed seed per acre, in which case, adding the typical manure in the New York study would increase the weed seed bank by 15%, a noticeable amount. In fields with high seed populations in the seedbank, this addition would be less noticeable. Conversely, this addition would result in dramatic increases in weed populations in relatively clean fields.

This New York study seems to contradict earlier reports leaving us with less assurance that ensiling, digestion and manure storage will greatly reduce or eliminate weed seed viability. Given that the New York work was conducted with current farming practices, one cannot discount the seriousness of weed seed contamination in manure in today's livestock systems. Earlier studies do, however, indicate that ensiling or passage through poultry does destroy many weed seeds.

An equally serious consideration is the introduction of new weed species. Velvetleaf became widely distributed in New York from feed grains purchased from the Mid-west in the 1970s. We believe the migration of velvetleaf northward in Wisconsin and Minnesota has primarily been the result of contaminated feeds.

Composting Manure

Composting is a biological process where the mechanical mixing of manure incorporates air into the manure pile, which in turn, stimulates the decomposition of manure to organic materials, such as humus. The effectiveness of composting manure as a means to kill weed seed depends on the temperature generated by the heating process, available moisture, and the species of weed seed present. Texas A&M scientists found that if composted manure with 35% moisture reached 120°F for three days, barnyardgrass, pigweeds and kochia seeds were killed (Wiese *et al.* 1998). Additionally, Johnsongrass seed was killed with three or more days of exposure at



Haubenschild digester barn and electrical generation building is shown above. Dennis Haubenschild (right) visits with field day tour participants.



Table 2. Average cumulative weed seed germination for two seasons in a field assay when planted following 20 days storage in manure with or without anaerobic digestion. 2002 - 2004. St. Paul, MN. (Katovich and Becker 2004).

Manure/Fertilizer Treatment	Germination by Weed Species (%)					
	Vele ^a	Colq	Rrpw	Lath	Gift	Wipm
Manure with anaerobic digestion	16	12	1	0	0	0
Manure without digestion	12	18	5	0	0	0
Untreated inorganic fertilizer control	14	11	4	0	0	0
LSD (P=0.05%)	NS ^b	NS	NS	NS	NS	NS

^a Vele = velvetleaf, Colq = common lambsquarters, Rrpw = redroot pigweed, Lath = ladysthumb smartweed, Gift = giant foxtail, Wipm = wild proso millet. Mean of 4 reps of 100 seeds for each species. All seed were pretreated with rumen fermentation.

^b NS = no significant difference.

160°F, but 7 days at 180°F was needed to kill field bindweed seeds. In contrast, they showed the importance of moist manure in seed death in that seeds of all species survived a 140°F temperature for 30 days if not mixed with manure but heated in dry air. Raising the dry air temperature to 160°F for three days killed all seeds except field bindweed. They concluded that composting will kill all weed seeds if the temperature is at least 180°F for longer than three days and that such compost would be safe to use on lawns, nurseries and agricultural land without fear of spreading weed seeds.

Work in Nebraska showed that moist compost killed cocklebur, morning-glory, pigweed, sunflower, velvetleaf, foxtail, smooth brome and shattercane faster and more completely than dry compost, in part due to increased compost temperatures when moist (Eghball and Lesoing 2000). In contrast to the Texas A&M study, the methods used in the Nebraska study were essentially those of on-farm composting comparing water added to dry composting. One week after weed seed placement, compost piles were turned. All seed in moist cattle manure were dead, while most seed in the dry dairy and dry beef manure were still alive.

Adding water to beef manure greatly enhanced the destruction of weed seeds. All weed seeds in the dry dairy manure eventually did die after 4- to 5-months of composting, with the exception that 14% of velvetleaf seed were still viable.

Some seed death occurred even though the temperature of dry compost windrows never exceeded 140°F, the temperature assumed necessary to kill weed seed. The authors concluded that composting that generates high temperatures (above 140°F) can destroy seed viability after only one turning and that keeping compost moist for most of the composting period reduces weed seed viability even though the critical temperature may not be reached. To put the benefits of composting into perspective, Chudney *et al.* (1992) noted the number of viable weed seed in California dairies was reduced from approximately 11,000 per ton to 300 to 4000 viable seed per ton through composting. They recommended that dairies compost longer than the typical 6 to 8 weeks, in deeper piles, and to add supplemental water to increase temperatures.

Based on these studies, we conclude that moist compost with temperatures above 140°F for two weeks should kill

most weed seed. Some hard-seeded weeds such as velvetleaf and field bindweed would require temperatures in the range of 160 to 180°F and longer composting times to kill all seed.

Anaerobic Digesters

Confined animal operations are coming under increased regulatory pressure to manage animal manure in ways that minimize environmental problems and reduce odors. This has increased interest in anaerobic manure digestion. This process biologically converts manure under anaerobic conditions into an effluent with properties that differ from raw manure, produces methane, which can be converted into electricity, and greatly reduces manure odor.

A University of Minnesota study assessed the effect of anaerobic manure digestion on weed seed survival (Katovich and Becker 2004). In the fall of 2001 and 2002, seed of 6 weed species were subjected to rumen fermentation and a subset of seed placed in a plug-flow anaerobic digester for 20 days (the length of time for one batch of manure to pass through the digester), and another subset stored for the same time period in the manure collection pit before entering the digester. A field germination assay was conducted by removing sod from a long-term bluegrass area to expose bare ground. The retrieved seed and digested or non-digested manure were fall-applied to the bare ground at 6000 gallons/acre. A subset of weed seed not stored in manure was applied with inorganic N fertilizer as a control. Weed emergence was monitored for next two growing seasons.

Viability of weed seed used in this study ranged from 82% for wild proso millet to 99% for velvetleaf and germination ranged from 1 to 14% in preliminary tests. The rumen treatment appeared to have killed all the

Table 3. First- compared to second-season cumulative velvetleaf seed germination for two growing seasons after planting following 20 days of fall storage in manure with or without anaerobic digestion. 2002 - 2004. St. Paul, MN. (Katovich and Becker 2004).

Manure / Fertilizer treatment	Cumulative velvetleaf germination (%)	
	First season	Second season
Manure with anaerobic digestion	14	2
Manure without digestion	6	6
Untreated inorganic fertilizer control	9	6
LSD (0.05)	3	3

giant foxtail, wild proso millet, and ladythumb smartweed seed, since none germinated in the inorganic fertilizer control (Table 2).

Some velvetleaf, common lambsquarters, and redroot pigweed survived the rumen treatment, but manure management did not alter germination of surviving seed compared to that of the inorganic fertilizer control. Temperatures in the anaerobic digester where the seed were placed ranged from 95 to 100°F, well below the 140°F required to kill weed seeds.

Although velvetleaf seed germination was not altered by digestion when averaged over the entire sampling period (Table 2), the rate of germination was accelerated with a higher percentage of digested velvetleaf germinating the first season compared to conventional manure or inorganic fertilizer treatments (Table 3). This may reduce velvetleaf problems in the future if emerged seedlings are effectively managed the first season since seed dormancy perpetuates annual weed problems. Velvetleaf seed appeared to be “primed” for germination as a result of anaerobic digestion.

Anaerobic manure digestion did not kill or reduce germination of weed seeds in this study, however, this process clearly reduced odor and generated sufficient electricity through methane conversion to not only run the

operation, but also with excess electricity to sell. The possibility that anaerobic digestion might kill seed in spilt-feed was not tested, since all seed were exposed to rumen digestion.

Contrast this with results of research in the Czech Republic (Sarapatka *et al.* 1993) where weed seeds of eight species were placed at two depths in simulated anaerobic digester tanks for approximately 30 days (Table 4). Passage through dairy cows did not kill all weed seeds of any species but effectively reduced viability of lambsquarters and barnyardgrass. Some weed seeds at the 16-inch depth survived digestion but no viable seeds

were found at the 70-inch depth near the bottom of the tank. These differences were attributed in part to higher initial temperatures at the 70-inch depth.

Jeyanayagam and Collins (1984) compared weed seed survival in batch and daily-fed 3-liter jar simulated digesters maintained at 95°F. After simulated rumen treatment followed by 15 to 20 days in a digester, weed seed viability of Johnsongrass dropped 18 and 82% and fall panicum dropped 24 and 76% for dormant and non-dormant seed, respectively. Anaerobic digestion killed roughly 3- to 5-times more non-dormant seed than dormant seed.

The three anaerobic digester studies differed significantly in design: the first used an operational flow through digester but placed seed artificially at a mid-depth at the end of flow; the second used a batch digester with initial higher temperatures in the bottom layers which all weed seed may not be exposed to; and the third study, simulated digestion and used only grass species, which often have seeds

Table 4. Weed seed viability when seeds were fresh, after passage through milking cows, and after one-month fermentation at two depths in a methane generator (Sarapatka *et al.* 1993).

Plant species	Fresh	After passage	After digester ^a	
			16" deep	70" deep
			Germination ^b (%)	
Barnyardgrass	94	5	36	0
Quackgrass	96	13	0	0
Wild oat	88	N/A	0	0
Lambsquarter	90	3	9	0
Pigweed	74	13	4	0
Pennycress	98	35	0	0
Smartweed	91	50	0	0
Curly dock	96	91	19	0

^a Temperatures of 86° F at 16" and 113 to 122° F gradually declining to 86° F at 70".

^b Though authors labeled as germination, appears to be viability, the sum of germination following repeated stratification and seeds that did not germinate but remained firm to the touch.

that are easier-to-kill compared to broadleaf species. Regardless, in all three anaerobic digestion studies significant numbers of weed seed survived which, when scaled up to field-scale operations, would pose a risk of increased weed problems in the field.

Summary

Avoid feed high in weed content. Livestock vary on the effect their digestion has on weed seeds, but all decrease weed seed viability. Well executed composting destroys most weed seeds. Weed species with hard seed coats like field bindweed and velvetleaf present the greatest risk of surviving composting. However, if the compost is moist, reaches the desired temperature, and completes its full cycle of decomposition, even seeds of these species are killed. Anaerobic digesters offer significant benefits in odor reduction and power generation, but will not offer the complete kill of weed seed afforded by well executed composting. Still, if the weed content of feedstock is known, particularly if produced on the same land where manure will be utilized, the benefits of anaerobic digesters in odor reduction and power generation likely outweigh the risks of potential survival of weed seed and resultant potential for increased weed pressure in the field.

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