Appendix 2

Cost/benefit comparison of five key solid manure management systems

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NB: This document is intended as a simple summary. For detailed discussion and evidence, see Appendix 1 (Literature Review)

	Manure management system				
Aspect	**Bokashi + EM** (Sealed fermentation of manures, with or without bedding treatment first)	**EM in Bedding only** (*in-situ* treatment then stacking uncovered)	**Uncovered Storage** (No EM, No plastic cover)	**Covered Storage** (No EM, Plastic Cover)	**Windrow Composting** (Aerobic Turning)
Direct costs	**Moderate** – requires purchase of: inoculant (≈£1.50/t of manure for Actiferm®); airtight bags or plastic covers. Additional additives (e.g. bran or molasses) sometimes also used.	**Low** – requires purchase of inoculant (Actiferm®) (≈£1.50/t of manure per application for four or more applications per season). Bedding cost otherwise unchanged.	**Lowest** - no cost other than for removing manures from the sheds (as for all the other systems).	**Low** – cost of impermeable sheeting or covers (re-usable). No special additives. Possibly minor cost for weights/ties to secure covers.	**Moderate to high**, depending on the type of machinery available to complete the turning process. Main costs are machinery/fuel for turning. Additives and inoculants optional.
Labour and time	**Labour:** Low to moderate. Must apply Actiferm® either repeatedly onto bedding during use or once and thoroughly mixed mucking out sheds. Amount of labour required depends on methods used. No labour required once manure heaps are sealed using plastic. Some effort may be required to collect and deal with leachate and to later open/handle fermented material. **Time:** Fast processing (ferments in ~4–8 weeks).	**Labour:** Low to moderate. Must apply Actiferm® repeatedly onto bedding during use. Amount of labour required depends on methods used. No labour required once manure heaps are stacked uncovered. Some effort may be required to collect and deal with leachate and to later handle partially fermented material. **Time:** Manure is likely to break down faster than non-Bokashi-treated manures, but data is lacking.	**Labour:** Low. Manure and bedding is removed from the shed in common with all other methods, then simply left, with no covering and no turns needed. **Time:** Variable, most farmers leave unturned manure heaps for between 6 months and 2 years prior to spreading.	**Labour:** Low, but higher than uncovered storage. Manure and bedding is removed from the shed in common with all other methods, then covered and left, with need to turn. **Time:** Variable, most farmers leave unturned, covered manure heaps for between 6 months and 1 year prior to spreading.	**Labour:** High. Requires frequent turning over at least 2 – 6 months. Regular monitoring is required to confirm that temperature and moisture remain in appropriate ranges. Time may also be required to create a level surface with leachate collection system for compost production and to engage with the regulator if bringing in wastes from outside the farm. **Time:** Slow process – typically 3–6 months to mature.

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Animal health and welfare (where Actiferm® is used in housing)	Limited evidence that animal health and welfare is improved where EM® or Actiferm® is sprayed on bedding during housing, though some farmers claim that this is the case.		N/A	N/A	N/A
Nutrient and carbon retention	**High** - sealed, anaerobic fermentation "locks in" nutrients. In particular, losses of N through leaching and volatilisation are minimised. Losses of carbon (as carbon dioxide) are minimised and therefore the amount of organic matter left for land-spreading is maximised. Some studies have shown that Bokashi manures can contain more (total) N than compost or untreated manure but further proof is required.	**Moderate to high** - there is some evidence that manures prepared with EM®-treated bedding tend to retain more nutrients and carbon than than untreated manures, but that evidence is less convincing where the manure is not covered and sealed for a fermentation period prior to use. Manure heaps which are not covered with an impermeable membrane are likely to lose more nutrients during storage than those which are covered.	**Low** - there is greatest potential for nutrient losses through leaching and volatilisation where manure heaps are open to the air and subject to rainfall ingress/egress. Similarly the potential for carbon losses through carbon dioxide emissions are highest in uncovered heaps.	**Moderate to high** - simply covering manure with an impermeable membrane is likely to reduce losses.. Covers prevent rain from causing nutrient runoff (leaching) and create barriers, which reduce emissions of ammonia, methane, nitrous oxide and carbon dioxide. Some evidence suggests that simple covers are not as effective as Bokashi treatment plus covers at conserving nutrients and carbon.	**Low** - aerobic composting typically results in a substantial loss of mass, carbon (through CO_2 emissions), nitrogen (through ammonia, and nitrous oxide emissions and through leaching of nitrate) and other nutrients such as potassium and sulphur through leaching. As much as 50–65% of carbon and 15%+ of nitrogen can be lost during windrow composting of manure.

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Odour and ammonia emissions	**Lower than untreated manures.** There is evidence that odours (particularly ammonia smells) are reduced in animal housing where EM® or Actiferm® is sprayed on bedding during housing. Odours from finished Bokashi manures are anecdotally also reported to be lower than those from untreated manures, whether they have been covered or not. There is some scientific evidence that ammonia emissions are reduced from livestock housing and from manures during preparation where EM® or Actiferm® is used to inoculate the bedding and /or manures.		**Moderate.** All animal manures will have an odour, but those containing relatively more carbon (compared to nitrogen, (e.g. strawy cattle manure) will be lower than those containing less carbon compared to nitrogen (e.g. poultry or pig manures). All manures will tend to smell most when they are being moved or spread.	**Low to moderate odour.** While all animal manures will have a distinctive smell, covering them during storage will reduce odours during that period. However, odours will be just as great (or even greater) than uncovered non-Bokashi manures during movement or spreading, because ammonia and other odorous gases trapped by the cover will be released.	**Has high potential for strong odours.** Windrow composting, especially of high-N manures, can release strong ammonia smells and other offensive odours (volatile organic compounds) as it decomposes in the open air and particularly during turning and especially during the early stages of composting.
GHG Emissions	**Lowest GHG footprint.** Bokashi system introduces microorganisms that break down wastes without producing methane or significant amounts of other greenhouse gases and also through covering, minimises greenhouse gas emissions during fermentation.	**Not known.** Actiferm applied to bedding only may result in reduced greenhouse gas emssions, but there is limited evidence of this. Emissions are likely to be higher than in sealed manure heaps, even when the uncovered heaps are thoroughly compacted.	**Moderate to high** – as well as being a source of ammonia (not a greenhouse gas), uncovered manure heaps are likely to be a source of methane, carbon dioxide and nitrous oxide. The extent of emissions will depend mainly on heap construction methods and weather conditions during storage.	**Lower GHG (vs. open storage).** Covering manure heaps primarily reduces ammonia emissions (air quality), but it also reduces GHG emissions. Overall, studies indicate covering solid manure can cut GHG emissions significantly relative to an uncovered, frequently disturbed pile.	**Highest GHG emissions.** Traditional composting has been shown to emit significantly more GHGs than Bokashi-treated waste, particularly when emissions from machinery operations are included.

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Ease of spreading	**Good** – better than standard manures	**Not known**, although some farmers claim this is better than standard manures	**Variable** - Depends on length of storage period, weather conditions and manure type.	**Variable** - Depends on length of storage period, weather conditions and manure type.	**Excellent** – There is less to spread for a given starting weight and the material is easy to spread evenly.
Emissions / nutrient losses during spreading	**Moderate to low** – Bokashi manure treatment is intended to reduce nutrient losses during preparation of the manures for spreading. However, the potential for nutrient losses during spreading can be greater than for standard, particularly uncovered manures. It is therefore very important that farmers apply Bokashi manures according to best agricultural practice.	**Not known**	**Moderate to low** - The potential emissions and nutrient losses from spreading of solid animal manures are well understood and there is good guidance to help farmers reduce losses and maximise manure nutrient value.	**Moderate to low** – Covering of manure stacks is intended to reduce nutrient losses during storage. However, the potential for nutrient losses during spreading can be greater than for uncovered manures. It is therefore particularly important that farmers apply these manures according to best agricultural practice.	**Low** – Although this is because compost is stable due to the emissions already having happened during the process.
Mass of manure remaining after treatment	**High** – There should be very low losses in mass or volume following treatment, other than where (nutrient-rich) leachate is removed during treatment.	**Not known** – No studies were found which compared the weight or volume of EM®-treated bedding and manure mixtures which were stored uncovered prior to use.	**Moderate** – While reports of the degree of losses vary, the volume and mass of uncovered manure is usually less after than before storage, as a result of losses of carbon, plant nutrients and in some cases, water.	**High** – There should be very low losses in mass or volume following treatment, other than where (nutrient-rich) leachate drains from the base of covered heaps during storage.	**Low** – mass losses of between 40 and 60% are common following composting processes.

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Total nutrients and carbon remaining in the heap as a whole	**Almost all** – due to the negligible losses of mass, almost all of the nutrients and carbon remain after fermentation, thus maximising the £ value of farm-produced manures.	**Not known**	**Not known** - While some losses of nutrients, carbon and water are inevitable, the extent of these losses will vary depending on the type of manure and the weather conditions during storage.	**Almost all** – due to the negligible losses of mass, almost all of the nutrients and carbon remain after fermentation, thus maximising the £ value of farm-produced manures.	**Significant losses** of carbon (as carbon dioxide and potentially methane) are inevitable, along with likely losses of nitrogen and potentially other nutrients through leaching and volatilisation.
Nutrient content within a tonne of manure	**Good** - There is some evidence to suggest that more nutrients are preserved in each tonne, when manures are prepared for spreading by sealed fermentation. There is also limited evidence to suggest that Bokashi manures can contain a greater proportion of nutrients in plant-available forms.	**Not known**	**Good** - There is no conclusive evidence to show whether more nutrients are preserved in each tonne, when manures are covered during storage. There are published standard values for the nutrient content of standard manures but they do not differentiate between covered and uncovered manures. Farmers are always advised to test their own manures, which can vary considerably.		**Not known** - There are published standard values for the nutrient content of standard manures but not for composted manures. These would vary widely depending on the starting material and the composting technique, therefore the farmers producing them would be advised to test their own.

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Practical issues	Applying EM® (Actiferm®) to bedding before, during or after use (i.e. with manure included) is simple and involves spraying or sprinkling dilute solution over the material. The practice works well in straw or woodchip-bedded housing for pigs, cattle, sheep or poultry and on mixtures of manure and bedding. Sourcing EM® (Actiferm®) and applying it uniformly is an added task, but advocates tend to find it straightforward. One limitation is that EM®'s effectiveness depends on creating a moist, anaerobic micro-environment in the bedding; if the bedding is too dry or too frequently disturbed, the inoculated microorganisms may not thrive. EM® solutions (being live cultures) have a shelf life. They should be stored according to the manufacturers instructions (i.e. not frozen or left in extreme heat).		The easiest, simplest and cheapest method, which is still that most commonly used by UK farmers. It is relatively easy for farmers to comply with UK regulatory requirements for siting and managing manure heaps.	Covering manure heaps is a straightforward practice recommended in codes of good farming practice. Appropriate materials and management are needed to make it work. Farmers must invest in sufficiently large, durable plastic or geotextile covers, which must be well-secured (tyres, sandbags, or straps) to prevent wind from blowing them off and to prevent livestock and wild animals causing damage. If the heap is added to over time, the cover has to be peeled back and re-secured with each addition – which can time-consuming.	Animal manures do not compost well because they are usually too wet, too dense and contain too much nitrogen relative to carbon. The effort and cost to produce composts from animal manures is high in terms of labour and dedicated machinery, which should at least include a compost turner and temperature monitoring equipment. Additional, high carbon feedstock may also be required in order to improve the physical properties of the manures for composting. This may have to be imported, which brings a significant regulatory burden.

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Practical issues (continued)	Other materials including seashell grit, lime and clay minerals may be required in order to ensure optimal fermentation if Actiferm® is applied only once prior to sealing of the heap(s). The process, which is similar to silage making, requires air-tight containment (e.g. bins or heavy plastic sheets or tubes) for fermentation. Batches might vary in size from a few tonnes up to thousands of tonnes. Farmers must be aware of safety issues (handling large covers) and reusability. Heavy-duty sheets can be reused for several years, making their use cost-effective, but they must be stored away from sunlight when not in use.	The Bokashi system is designed to work in sealed systems and there is little evidence of benefits where EM®-treated manure is left uncovered in sheds or in a field heap. The advantages of Bokashi treatment are thought to reduce if the manure is allowed to start decomposing in ways other than fermentation.	This method is most widely used in the UK. Practical issues are well understood.	Rainwater management is important: covers keep rain out of the manure (good for preventing leaching), but the rain has to go somewhere, so heaps should be placed on a slight slope or drainage should be provided to handle runoff. Farmers must also be aware of safety issues (handling large covers) and reusability. Heavy-duty sheets can be reused for several years, making their use cost-effective, but they must be stored away from sunlight when not in use. Covering on its own won't completely address issues such as animal pathogens and weed seeds in the way that composting and to a lesser extent, fermentation will.	Composting should be conducted on a dry, level surface and the regulator may require that it is done on an impermeable bund with leachate collection, which makes it very expensive. Composting manures is particularly difficult in wet season, when it can be impossible to achieve sufficiently high temperatures and leachate production can be high. Most farmers who try composting decide that the effort is not worthwhile. It is only truly worthwhile where farmers want a stable, sanitised material suitable for high value crop production.

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Practical issues (continued)	Excess moisture leads to a nutrient-rich leachate that should be captured (to avoid pollution) and ideally reused on fields. In cold climates, fermentation may be slow, so insulating the heap or fermenting indoors can help.			UK regulations are likely to result in universal covering of manure stores in the future.	