HOUSING DECISIONS FOR THE GROWING PIG

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ABSTRACT

Housing decisions for the growing pig involve more than the typical decisions of full versus partial slats and curtain sided versus mechanically ventilated. Decisions on feeder and drinker design impact both the capital cost of facilities and pig performance once the facilities are constructed. There is renewed interest in large group pens (over 100 pigs per pen) and the impact of management decisions on the effects of various space allocations in the nursery and grow-finish. Large pen sizes along with modifications to space allocation are typical for many wean-to-finish facilities. In both wean-to-finish and conventional systems, previous recommendations to sort by size at placement are being challenged by new data which suggests that variation within a pen of pigs is more beneficial to overall performance of a population of pigs than sorting by size at placement. Management of variation in growth by removal of smaller pigs and placement of these pigs with like size pigs has also been demonstrated to have no effect on overall performance of a population of growing pigs.

INTRODUCTION

To understand the great strides that have been made in grow-finish swine production, one only has to look at the differences in performance at a University of Nebraska swine research center from 1982 and 2002 as presented in Table 1. For both 1982 and 2001, pigs were reared in the same partially slatted confinement facility and fed corn-soybean meal diets in meal form. In 1982, pigs were given 0.83 m^2/pig and three feeder holes per 10 pigs, while in 2001, they were given 0.69 m^2/pig and two feeder holes per 12 pigs.

Table 1. Improvements in pig performance at a University of Nebraska swine research facility.

Item	1982[a]	2001[b]
Initial wt, kg	22.3	28.1
Final wt, kg	93.6	118.2
Daily gain, kg	0.680	0.886
Daily feed, kg	2.27	2.40
Feed:gain	3.34	2.70

[a]Brumm et al, 1982; [b]University of Nebraska Experiment 01306, unpublished

There can be many reasons cited for the vast improvement noted, but several that must be considered include genetics, health, nutrition and feeder design. To separate out the impact of feeder design from all of the other contributing factors, Table 2 was prepared comparing recent performance in the same partially slatted research facility before and after feeder replacement. The improvement in feed conversion efficiency is striking, even when corrected for the differences in sex (barrow vs. gilt) and feed form (meal vs. pellet).

As a consequence of data such as this, producers and their advisors are paying much more attention to design details when purchasing feeders and locating them in the pig's environment.

Table 2. Impact of feeder replacement on pig performance.

Item	Old feeder[a]	New feeder[b]
Initial wt, kg	30.7	36.1
Final wt, kg	95.5	98.6
Daily gain, kg	0.927	0.882
Daily feed, kg	2.51	1.83
Feed:gain	2.72	2.09
Sex	Barrow	Gilt

[a]Brumm, 2002; [b]University of Nebraska Experiment 01305, unpublished

NUMBER OF FEEDING SPACES

Traditionally, advisors to the swine industry have recommended one feeding space per four pigs for the growing pig and one feeding space for four or five pigs for the finishing pig (MWPS, 1991). However, this recommendation makes no mention as to the dimensions of the space, the location of the space within the animals environment, or other factors that influence the growing pigs interaction with the feed delivery device. Australian guidelines are somewhat more specific by recommending one space for four growing pigs with the space recommended to be 250 mm in length (Farrin, 1990). The European recommendation is one space per four pigs with the space averaging 59 mm/pig for 50-kg pigs and 74 mm/pig for 100-kg pigs (English et. al., 1988).

Research on feeder space allocations is surprisingly limited. Wahlstrom and Seerley (1960) concluded that one feeder space per six pigs within the weight range for 30 to 91 kg was probably adequate. Using 12 pigs per pen, Wahlstrom and Libal (1977) concluded there was no difference in performance when three, four, or six pigs were allotted for each available feeder space when wooden feeders were used as the feed delivery device for pigs from 28 to 70 kg.

McGlone et. al. (1993) provided one, two, or three feeder spaces for 20 pigs per pen from 61 to 104 kg live weight. Using a meal diet, they concluded that the feeder space requirement is one space per ten pigs. Bates et. al. (1993) in a study at a commercial swine finishing unit, also concluded that growing-finishing pigs can be stocked at a rate of ten pigs per feeder hole.

Morrow and Walker (1994) recommended that two, single-space feeders be used in pens of 20 finishing pigs when meal diets are available ad libitum. They also recommended that the feeders be sited some distance apart (> 2 m), not side by side when pigs are provided 0.60 m″ per pig pen space from 37 to 91 kg live weight. Growing pigs in this study showed a clear feeder preference, with a higher proportion of feed consumed from the feeder nearest the service passage.

QUALITY OF FEEDING SPACES

Although many feeders have some type of feeder space division, they may not accurately reflect the true space requirements. Baxter (1991) suggested that the minimum width of a feeding space should be the shoulder width of the pig, plus 10% to accommodate pig variability and movement. The shoulder width of a pig, in centimeters, is approximately $6.1 * BW^{0.33}$, with body weight expressed in kilograms (Petherick, 1983). Thus, the width of feeder spaces for 5-, 25-, 50-, and 120-kg pigs would be 11.1, 19.8, 24.8, and 32.8 cm, respectively.

Baxter (1991) also examined the preference of pigs to eat at different heights. Although pigs prefer to eat from a surface at or slightly above floor level, they can eat from levels as high as their shoulders. Some feeders may have an elevated feeding surface or feed access lever, which could limit feeding if these exceed shoulder height. Elevated feeding surfaces usually require pigs to stand at an angle to the feeder and rotate their heads when eating (Gonyou and Lou, 1998).

The depth of the feeder, from the lip at the front of the feeder to the feed access point at the back, determines the extent to which pigs will step into the feed bowl or trough while eating. When feeder depth was only 20 cm, approximately 50% of 20 kg pigs would step into the feeder while eating. For 95-kg pigs, none would step in at feeder depths of 20 cm, < 20% at a depth of 30 cm, and all of the pigs would when the depth was 40 cm (Gonyou and Lou, 1998). However, large pigs (95 kg) have difficulty eating from an area closer than 20 cm from the front of the feeder.

A compromise in feeder depth is needed when feeders are used over a wide range of pig body weights. Gonyou and Lou (1998) suggest that feeder depths for growing-finishing pigs should be 20 to 30 cm.

All of the design concepts discussed above assume that the pig is standing at right angles to the feeder. However, when pigs are allowed to eat feed placed on the floor along a wall, they stand at an angle of approximately 30^{o} from the vertical surface (Gonyou and Lou, 1998). Such a position may facilitate apprehension of the feed. It may be advisable to consider designs that provide such an angle to the feed access point.

FEEDER DESIGN AND FEED WASTAGE

The movements associated with feed falling onto the floor (feed wastage) were studied by Gonyou and Lou (1998). The most common movements associated with feed wastage were backing away from the feeder, eating while the head was raised, fighting, and stepping into the feeder. Two of these behaviors, fighting and stepping, were more common for smaller pigs that also waste a higher percentage of feed. Fighting was more common among smaller pigs as some of the feeders studied had wider feeder spaces than recommended and two pigs would eat from the same space. As indicated above, when feeders have depths exceeding 20 cm, as required for large pigs, small pigs must step into the feeder while they eat. The compromise required when a wide range of pig sizes is fed from the same feeder results in greater wastage by the smaller pigs.

Table 3 summarizes the critical dimensions for feeder design when the feeders will be used where pigs are given ad libitum feed access.

Table 3. Critical design dimensions for single and multi-spaced grow-finish feeders – ad libitum feed access.

Feeder Specification	Dimensions
Feeder space width	300-360 mm
Feeder lip height	100-125 mm
Feed trough depth	
Lip to delivery mechanism	200-300 mm
Number of pigs per space	
Dry feeder	10
Wet/dry feeder	12

WET/DRY FEEDERS

An alternative to dry feed presentation is to allow pigs to access both water and dry feed from the feeder, with the option to combine them before consumption. This is referred to as a wet/dry feeder. Various methods are used to provide access to feed in these feeders. Some feeders allow access to dry feed on an elevated platform or shelf. The pigs may eat from this shelf or push the feed into the bottom pan of the feeder where it can be combined with water. Another method of accessing dry feed is to press a lever or bar that drops feed into the feeder pan. Water is normally available from a nipple that may be oriented downward or horizontally. A key feature to wet/dry feeders is that there is a separation of the water from the access point of the dry feed. Otherwise the water will "wick" into the feed storage and plug the feeder.

Walker (1990) reported an increase in daily gain and feed intake when water was available at the feeder vs located 3 m distant from the feeder. Patterson (1991) reported no benefit to pig performance for wet/dry feeders.

The decision on wet/dry feeders vs. dry feeders and nipple drinkers located at a distance from the feeder is often based on issues not related to pig performance. Gadd (1988) summarized a series of on-farm experiences and concluded that slurry production was reduced as much as 50% with wet/dry feeders vs dry feeders. Maton and Daelemans (1992) concluded all wet-dry feeders reduce water spillage, resulting in a 20 to 30% reduction in slurry volume. Brumm et. al. (2000), using a two-hole wet-dry feeder for 24 pigs per pen also reported a 30% reduction in slurry volume.

Both Rantanen et. al. (1995) at Kansas State University and Brumm et. al. (2000) at the University of Nebraska report a significant reduction in daily water use for pigs on wet/dry feeders vs. dry feeders and nipple drinkers separate from the feeder. The Kansas workers reported total water disappearance of 6.25 L/pig/d for the dry feeders vs. 4.16 L/pig/d for the wet/dry feeder from 48 to 83 kg live weight. The Nebraska workers reported total water disappearance of 6.06 L/pig/d for the dry feeders vs 4.50 L/pig/d for the wet/dry feeders from 19 to 108 kg live weight.

Several studies have indicated that one model of wet/dry feeder resulted in increased intake compared to a particular dry feeder (Anderson et. al., 1990; Walker, 1990). In a summary of several on-farm tests, Payne (1991) concluded that the wet/dry feature resulted in increased growth but no increase in apparent feed intake. However, he suggested that the level of feed wastage may have been less in wet/dry feeders and that actual intake may have been higher. Gonyou and Lou (2000) compared feed intake and growth from six models of wet/dry feeders with that of six models of dry feeders. The wet/dry feature resulted in a 5% increase in both feed intake and growth rate.

WATER USAGE

As noted above, the decisions as to feeder design often include considerations regarding water disappearance and manure volume. In a series of trials, Brumm et. al. (2000) investigated several feeder and drinker combinations for their impact on pig performance, water usage and resultant manure volume. (Table 4). While not directly compared, water savings (and resultant manure volume reductions) appear to be similar for the wet/dry feeder investigated and the dry feeder and cup drinker based on water:feed ratios.

Brumm and Mayrose (1991) examined the impact of flow rate and pigs per drinker on performance (Table 5). They concluded that while differences in performance existed between the research centers, a delivery rate of more than 250 ml/min is advisable for finishing pigs. The rate of 1000 ml/min appears to be more than adequate, especially if water conservation is a concern. The results also suggested that one nipple drinker per 16 or 22 pigs per pen was inadequate.

These results suggest total water disappearance is considerably less than the estimates currently in the literature. For example, the Midwest Plan Service (MWPS, 1991) suggest a growing-finishing pig uses between 12 and 16 liters of water per day. Recent Australian data reported 17 liters of water use for all purposes per kilogram of liveweight sold (Australian

Pork Limited, 2002). In the above experiments, maximum water used was just over 6 liters per pig suggesting considerable water usage on pig farms not associated with pig needs.

Table 4. Effect of feeder and drinker decisions on performance, water use and manure volume (Brumm et. al, 2000).

	Exp 1, Feeder type		Exp 2, Drinker type		Exp 3, Drinker type	
Item	Wet/dry	Dry	Swinging	Nipple	Swinging	Cup
Pig wt, kg						
Initial	18.6	18.5	18.2	18.3	17.5	17.4
Final	108.0	107.4	110.0	109.9	115.1	113.9
Daily gain, kg	0.780[a]	0.760[b]	0.754	0.748	0.831	0.820
Daily feed, kg	2.379[a]	2.250[b]	2.302	2.307	2.118	2.043
Feed:gain	3.049[a]	2.959[b]	3.086	3.058	2.551	2.494
Water, L/pig/d	4.49	6.06	4.90	5.50	5.01	3.78
Water:Feed, kg:kg	1.78[a]	2.79[b]	2.34[a]	2.64[b]	2.41[a]	1.89[b]
Manure volume, L/pig/d						
Summer	4.96	7.02				
Winter			3.96	4.59		

[a b]Means within experiment differ, P<0.05.

Table 5. Effect of flow rate and number of pigs per nipple drinker on finisher pig (59 to 105 kg) performance (Brumm and Mayrose, 1991).

		Flow, ml/min		Number of pigs/nipple	
Item	Location	250	1000	8 or 11	16 or 22
Daily Gain, kg					
0-28 d	University of Nebraska	0.727[a]	0.777[b]	0.790[c]	0.712[d]
	Purdue University	0.614	0.641	0.655	0.595
Overall	University of Nebraska	0.773	0.814	0.818	0.768
	Purdue University	0.645	0.650	0.655	0.641
Feed:Gain					
Overall	University of Nebraska	3.66	3.54	3.55	3.65
	Purdue University	3.61	3.59	3.54	3.65

[a,b]P<0.1; [c,d]P<0.05

REMOVAL AND REMIXING OF LIGHTWEIGHT PIGS

Managing variation in pig weight has major consequences for pig flow. Many producers routinely overstock pens at placement, sorting off the lightest weighing pigs and remixing these pigs at some point during the first three to eight weeks following placement. They follow this management practice in the belief that removing the lightest pigs from a pen and remixing with other lightweight pigs results in better overall pig performance for the population of pigs placed in the facility and possibly better facility utilization.

Recently, the NCR-89 Committee on Swine Management tested this management practice in both wean-to-finish and grow-finish production flows (Brumm et al, 2002). In two experiments, the following treatments were applied to populations of pigs:

1) 15 pigs/pen from initial weight to slaughter (15S),
2) 20 pigs/pen from initial weight to 3 weeks post weaning for wean-to-finish or the week the population weighed 68 kg for grow-finish and then reduced to 15 pigs/pen to slaughter (20/15), and
3) 15 pigs/pen comprised of the 5 lightest pigs from each of three 20/15 pens (15M).

In each study, corn-soybean meal diets were based on the mean weight of the population of pigs, rather than based on individual pen weights. Thus, the lightweight pigs did not receive any special diet or other management following remixing, a practice that is typical of many production facilities.

The populations compared were the population that was sorted and mixed (20/15 + 15M) versus the population that was never sorted (15S). Sorting the lightest weight pigs was effective in reducing the within pen weight variation at the time of sorting (Tables 6 and 7), but had minimal effect on reducing within pen weight variation at day 158 post weaning for the wean-to-finish trial or when the first pig in the pen weighed at least 114 kg for the growing-finishing trial.

Figure 1 displays the variation in pig weight of each population on day 158 when the heaviest pigs in the wean-to-finish facility were removed for slaughter. The sorted and mixed population is represented in both ends of the population weight curve, while the unsorted population is not represented in either the two lowest weight or the heaviest weight groupings.

Table 6. Effect of sorting and removal on wean-to-finish pig performance (Brumm et. al, 2002).

	Treatment		
Item	20/15	15M	15S
Pig weight, kg			
Weaning	4.8		4.8
Day 21 - presort[a]	9.0		9.5
Day 21 - postsort[b]	9.7	7.0	9.5
Day 158 post weaning[a]	116.9	110.5	115.1
Coefficient of Variation (pig weight within pen), %			
Day 21 – presort	19.5		17
Day 21 - postsort[b]	13.7	11.3	17
Day 158 post weaning	7.6	7.9	6.9

[a] Treatment effect, $P<0.05$
[b] 20/15+15M vs 15S, $P<0.01$

Table 7. Effect of sorting and removal on finishing pig performance (Brumm et al, 2002).

Item	Treatment 20/15	15M	15S
Pig weight, kg			
Placement	26.2		26.2
Presort and removal	72.9		70.8
Postsort and removal[a]	74.1	61.6	70.8
Coefficient of Variation (pig weight within pen), %			
Placement	13.4		13.3
Presort and removal	10.2		11.4
Postsort and removal[b]	9.2	8.6	11.4
First pig removed[b]	8.2	8.7	10.2

[a] Treatment effect, P<0.01
[b] 20/15+15M vs 15S, P<0.05

Figure 1. Effect of sorting and mixing treatments on pig weight on day 158 post-weaning in a wean-to-finish facility (Brumm et. al, 2002).

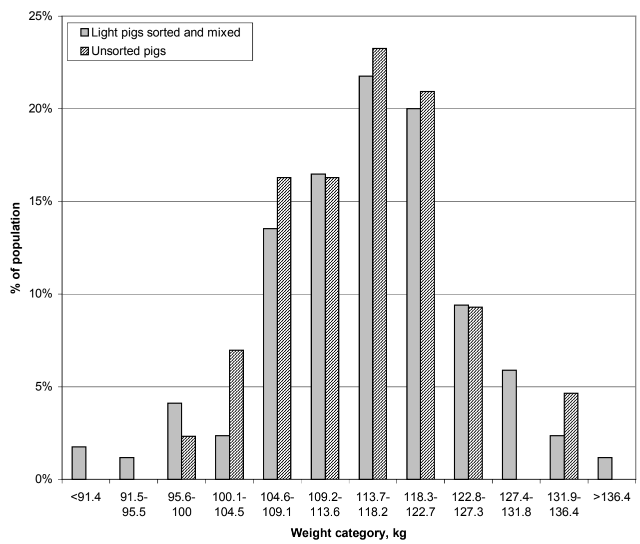
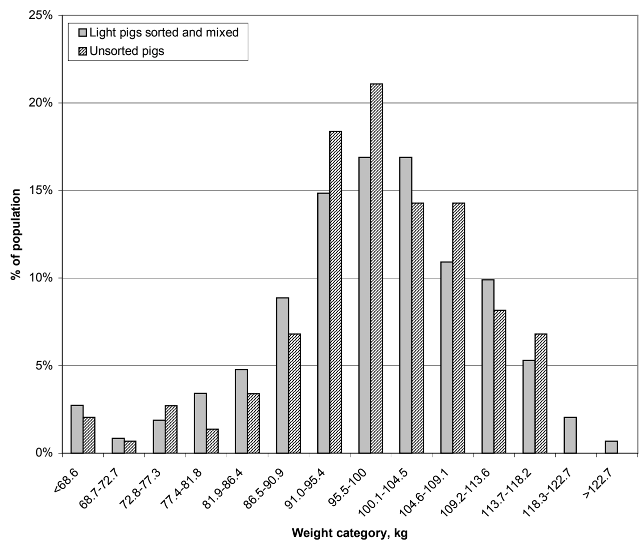


Figure 2 is a similar display of weight variation in each population when the first pig was removed on the week it weighed 114 kg or more for the grow-finish trial. This data has more spread since it represents the combined data of pigs at the University of Nebraska, University of Minnesota, University of Illinois and Iowa State University. However, the overall pattern is the same. That is, no pigs in the unsorted population were in the heaviest weight category and a greater number of pigs in the lightest weight categories. In the grow-finish study, 14% of the pigs in the sorted population weighed less than 87 kg versus 10% of the unsorted population.

Figure 2. Effect of sorting and mixing treatments on pig weight the week the first pig in a pen weighed at least 114 kg, grow-finish study (Brumm et. al, 2002).



In the grow-finish study, pigs were removed for slaughter on the week they weighed 114 kg or greater. Beginning the week when 50% or more of the pigs had been removed from a pen, the remaining pigs were fed for up to 3 weeks or until the pen averaged 114 kg. Using this method to market pigs, the pens that had the pigs removed had average days to empty of 108 following placement, and the pens that had the mixed pigs had average days to empty of 125. This compares to a 118 day average days to empty for the unsorted pigs. In this study, it took 7 days longer (125 vs 118) to empty the last pen for the population of pigs that had the lightweight pigs removed and remixed versus the population where the lightweight pigs were not removed.

In these studies, removal and mixing of the lightweight pigs did not decrease the variation in population weight, nor did it improve facility utilization as measured by the days to pen empty in the grow-finish trial. There are several possibilities for why this common management practice is not effective.

When the lightweight pigs were removed and remixed, they had to learn new pen mates, pen social structure and new pen location. All of this probably contributed to a period of time in which there was minimal feed intake and growth. When they achieved a stable social structure, variation in the pen increased to that of other pens since some pigs in the pen became dominant, some submissive and some unsure as to their social status.

For the pens where the pigs were removed, similar social disruptions occurred. While the pigs remaining in the pen did not have to become acquainted with a new pen, the removal of the lightweight pigs most likely resulted in the removal of the lowest social ranking pigs. With their removal, one or more of the remaining pigs in the pen acquired the low social rank. This most likely explains why sorting and removal was not effective in changing within pen variations in weight at slaughter.

It is possible that results may have been different if the lightweight, remixed pigs had been offered a diet formulated to more closely match their nutritional needs versus a diet formulated to the average needs of the population. Results may also differ if the heaviest or midweight pigs are removed and remixed.

SORTING BY WEIGHT AT PLACEMENT

Another common management practice is to sort pigs by weight upon entry into wean-to-finish, nursery and grow-finish facilities. Producers do this in the belief that pens of pigs begun at uniform weights will have less variation at slaughter weight and may have better daily gain.

When this management practice was first utilized in confinement facilities, it made sense considering the farrowing/weaning practices common to the industry. When farrowing and weaning were continuous flow events on hog farms, sorting by size also implied a sorting by age. Thus, sorting by size was a management tool to minimize the age variation within a pen of pigs. However, in a majority of today's North American production systems, age variation with a facility is often minimal. It is not uncommon to put 1000 pigs into a growout facility with no more than 3 days in age variation among all the pigs.

Recent research has reexamined the practice of sorting by size at the time of placement. There are now several studies that have examined the impact of sorting pigs by size (light, medium and heavyweight or light and heavy) at placement versus placing light and heavy pigs in the same pen on performance to slaughter (Tindsley and Lean, 1984; Francis et. al, 1996; O′Quinn et. al, 2001).

Typical of these studies are the results of O'Quinn et. al. (2001) that are presented in Table 8. While sorting by size was effective in reducing the within pen weight variation at placement on day 0, there was no difference in within pen weight variation on day 91. Similarly, Tindsley and Lean (1984) reported that coefficients of variation for within pen weight didn't change from placement to slaughter when pigs were placed in pens with large weight variation initially. However, variation increased within pens when pigs were placed in pens with minimal within pen weight variation.

As a result of these data, the recommendation is to not sort pigs by size upon placement into a growing-finishing facility, nursery or wean-finish facility. The exception to this recommendation is when it is possible to use management tools to treat a group of sorted pigs in a special manner. For nurseries and wean/finish facilities, this means that it remains accepted practice to pen the very lightweight pigs together, in the expectation that they will remain on a starter diet sequence 1-5 days longer than the rest of the pigs in the facility. For grow-finish facilities where the nutrition, temperature and other management decisions are made on the basis of the average of the barn, sorting by size is not routinely recommended.

Table 8. Effect of sorting by weight at placement on pig performance (O'Quinn et. al. 2001).

Item	Treatment				P value
	Heavy	Medium	Light	Unsorted[a]	Sorted vs. Unsorted
Pig wt, kg					
Day 0	37.1	34.0	30.2	33.8	
Day 91	123.4	117.8	113.2	119.9	0.03
Within pen CV pig wt, %					
Day 0	3.4	2.3	6.8	9.4	
Day 91	6.0	6.5	8.2	7.3	
ADG, kg	0.94	0.92	0.91	0.94	0.03
ADF, kg	2.67	2.66	2.73	2.70	0.84
F:G	2.85	2.93	3.02	2.88	0.46

[a]Consisted of equal numbers of heavy, medium and light pigs within the pen

NEW THOUGHTS ON SPACE ALLOCATION

There is a vast amount of literature available on space allocation effects on performance. The earliest summary of the data was Kornegay and Notter (1984). Their literature review suggested that as space per pig declines, the largest effects are on daily gain and feed intake, with less predictable effects on feed conversion efficiency. The challenge for North American producers has been that Kornegay and Notter's review included no literature where pigs were grown to slaughter weights larger than 100 kg.

Since then, there have been several studies examining the effect of space allocation to heavier weights (NCR-89, 1993; Brumm and NCR-89, 1996). In addition, consideration is now given to the economic consequences of the space allocation decision (Powell and Brumm, 1992; Powell et. al, 1993). In general, the North American swine industry balances the reductions in performance with the economics of facility flow by stocking fully slatted barns at 0.69 m^2/pig.

However, recent research is causing many production systems to rethink the potential response to space allocation. Brumm et. al. (2001) suggest that the response to space allocation may depend on when the social group (pen mates) was formed. Their study examined the potential interaction of nursery space allocation and grow-finish space allocation when pigs are moved from the nursery to grow-finish at approximately 20 kg. When pigs were mixed and new social groups created upon movement from the nursery to the grow-finish facility, pigs responded to space restriction by reducing feed intake and daily gain (Table 9). However, when social groups remained stable (pens of pigs moved to grow-finish facility with no remixing), there was no effect of space allocation on gain, feed intake or feed conversion (Table 10).

Brumm et al. (2001) concluded that the literature available on the effects of space allocation (such as Kornegay and Notter, 1984) reported on trials where pigs were mixed at the beginning of the experiment to create uniform social groups. However, many production systems maintain pen identity (either by moving entire pens or as wean-finish) between nursery and grow-finish phases of production and thus may not experience as dramatic an effect of space allocation as predicted in the literature.

Table 9. Interaction of nursery and grow-finish space allocation when pigs are mixed at move from nursery (Brumm et. al, 2002).

	Space allocation, m^2/pig				P Values	
Nursery:	0.16		0.25			
Item Grow-finish:	0.56	0.78	0.56	0.78	Nursery	Grow-Fin
Pig wt, kg						
Weaning	6.6		6.6			
From Nursery	19.4		20.9		<0.001	
Daily gain, gm						
Nursery	364		408		<0.001	
Grow-finish	817	849	781	867		<0. 001
Grow-finish ADF, kg	2.533	2.589	2.465	2.665		0.002

Table 10. Interaction of nursery and grow-finish space allocation when pigs are not mixed at move from nursery (Brumm et. al, 2002).

	Space allocation, m^2/pig				P Values	
Nursery:	0.16		0.23			
Item Grow-finish:	0.60	0.74	0.60	0.74	Nursery	Grow-Fin
Pig wt, kg						
Weaning	5.4		5.4			
From Nursery	21.4		22.7		0.001	
Daily Gain, gm						
Nursery	403		430		0.001	
Grow-Finish	821	821	827	831		NS
Grow-finish ADF, kg	2.386	2.419	2.398	2.433		0.023

CONCLUSIONS

Housing decisions involve both decisions regarding capital expense such as feeders and drinkers and decisions regarding daily management such as sorting and mixing and removal for poor growth. As demonstrated by the data from the University of Nebraska, great strides have been made in grow-finish pig performance in the past 20 years. As we continue to learn more about the pig's behavioral preferences and its response to the limitations we may impose such as space or temperature, we can expect to see as great or greater improvements in the next 20 years.

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