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Pigs per sow per year has gradually, but steadily, increased in the U.S. during the last 15 to 20 years. More efficient use of better maternal breeds and lines, crossbreeding systems that efficiently utilize heterosis, and improved management and diets are causes for most of this improvement.

Genetic selection to further increase reproductive traits such as litter size and litter weaning rate has recently been implemented and may explain some of the increase in sow productivity in the latter years. However, efficient programs to improve sow reproduction have not been in place long enough to cause much change in the U.S. pig herd.

Continuous application of efficient selection programs in seedstock herds will be necessary to further improve reproductive performance. However, reproductive traits generally have low heritabilities and other traits also must be emphasized in selection programs. Selection accuracy has been increased through the use of computers and genetic analyses to estimate breeding values, but even when these procedures are used, the annual rate of change will not be great. Therefore, there is a need for procedures to speed the rate of improvement from genetic selection for reproductive traits.

Such a procedure was tested experimentally at the University of Nebraska. Selection was for an index of ovulation rate and embryonic/fetal survival rate measured at 50 days of gestation. The experiment was described, and results of the first five generations of selection were reported, in the 1988 Nebraska Swine Report. Selection was continued for another five generations and an additional generation with random selection was produced to evaluate the lines. The purpose of this article is to report the results of this index selection on ovulation rate and on litter sizes at 50 days of gestation and at birth and to briefly discuss the potential application of this selection method.

Materials and Methods

The experiment began in 1981. A composite population of Large White x Landrace cross was used. Littermates in the base generation were randomly assigned to the index line (I) or the control line (C). The selection index was: I_1 = 10.6 x Ovulation Rate + 72.6 Embryonic Survival Rate (generations 0 to 5), and I_2 = 10.6 x Ovulation Rate + 149 x Embryonic Survival Rate (generations 6 to 10).

Size of line I was 40 to 45 litters by 20 sires per generation. Each generation, all female progeny were mated (approximately 160 gilts) to 20 sons of the 15 females with the greatest index value. At 50 days of gestation, laparotomy, a surgical procedure in which the reproductive tract is exposed through the abdomen, was performed. Number of ovulation sites on the ovary and number of fetuses were counted. Embryonic survival was calculated as the ratio of number of fetuses to number of ovulations.

Gilts were ranked for the index and the 45 gilts with the greatest value were selected to farrow. All others were culled before they farrowed. Progeny of the selected females were mated for the next cycle of selection. Therefore, the selection rate was approximately 45 in 160 for dams of gilts, and 15 in 160 for dams of boars.

Line C was maintained with 40 to 45 litters by 15 sires per generation. At least one gilt was selected randomly from each litter and one boar was randomly selected from each half-sib family. Laparotomy was done in approximately half of line C gilts.

Pigs were weaned at 28 days of age, placed in a nursery and fed an 18% protein, corn-soybean meal diet to 56 days of age when they were moved to open front buildings with doors over side openings to regulate temperature and ventilation. They were in groups of 10 pigs per pen, and sexes were in separate buildings.

The diet contained corn or milo, soybean meal, and a vitamin-mineral premix, and was formulated to contain 16% or 14% crude protein. Pigs were switched to the 14% protein diet when the average weight of pigs in a pen was approximately 125 lbs. These diets and those described below contained amounts of vitamins and minerals recommended by NRC.

When gilts reached approximately 200 lbs, they were fed on the floor an amount that averaged 4.5 to 5 lbs of feed daily for each gilt in the pen. This regimen continued until 10 days before breeding began, when the daily feed allotment was increased to 6.5 to 7 lbs per day to cause the "flushing" effect on ovulation rate. After mating, gilts were placed in gestation stalls and given 4 to 4.5 lbs of feed per day during the last 30 days of gestation. The diet was formulated to contain 11.5% protein. Within three days after parturition, gilts were allowed *ad libitum* access to feed through the lactation period. The diet contained 13.2% protein and 4% tallow.

To better characterize responses to selection, generation 11 was produced with random mating, population size was increased, and randomly selected generation 11 gilts were mated and farrowed without imposing the laparotomy procedure. In the last generations of the experiment, there was an increase in the incidence of mummified pigs and stillborn pigs at birth in index line gilts compared to controls. These losses could have been due to the laparotomy procedure, which could have been more traumatic to the larger litters carried by index gilts, or these losses could be a natural phenomenon in index gilts with increased ovulation rate and litter size.

A nutrition experiment was imposed on generation 11 gilts to determine if the losses described above in the index line gilts could be reduced by increasing nutrients in the diet during the gilt development period beginning at 200 days of age through gestation. The diets compared had either 14% protein plus NRC amounts of vitamins and minerals, or 18% protein plus 50% more vitamins and minerals than those recommended by NRC.

Two lactation diets also were imposed, one had 15% protein plus NRC recommended amounts of vitamins and minerals, the other had 18% protein and 50% more vitamins and minerals than amounts recommended by NRC. All diets contained corn, soybean meal, beet pulp and premix. Lactation diets contained 4% tallow.

A total of 285 generation 11 gilts, 164 index line and 121 control line, were selected for this experiment when they were 56 days of age. Other than the change in diets and elimination of the laparotomy procedure, other management, including amounts of feed fed, were as described above for the selection experiment.

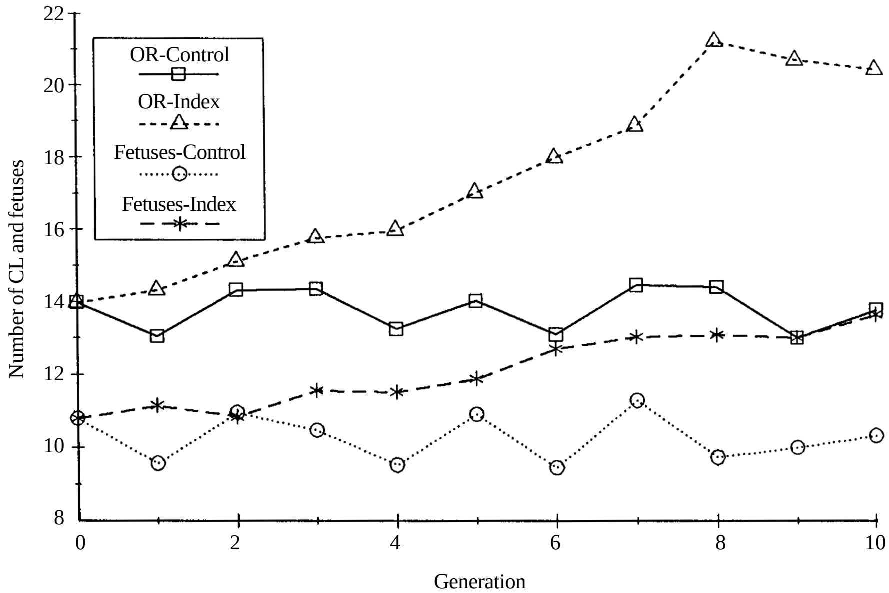

Figure 1. Number of corpora lutea (OR) and number of fetuses at 50 days of gestation

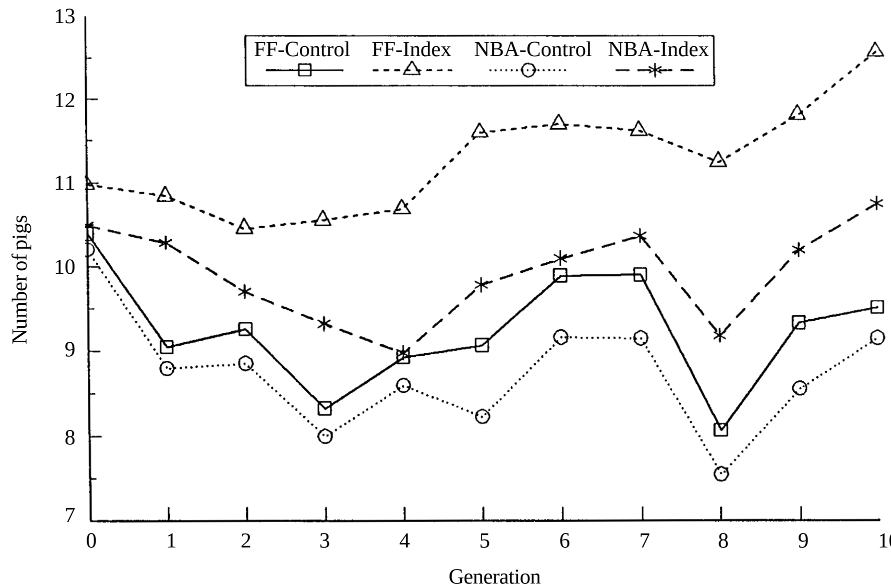

Figure 2. Number of fully formed pigs (FF) and number of pigs born alive (NBA)

Results

Selection Experiment. Line means for ovulation rate and number of fetuses at 50 days of gestation are illustrated in Figure 1. Over all generations, the response per generation (measured as the increase over generations in the difference between lines I and C) averaged .78 $\pm$ .04 ova and .32 $\pm$ .02 fetuses. Therefore, the total response after 10 generations was estimated to be an increase of 7.8 ova and 3.2 fetuses at 50 days of gestation. Embryonic survival actually declined at the rate of -.9$\pm$ .1% per generation.

Figure 2 illustrates the response in number of fully formed pigs and number of pigs born alive. The average

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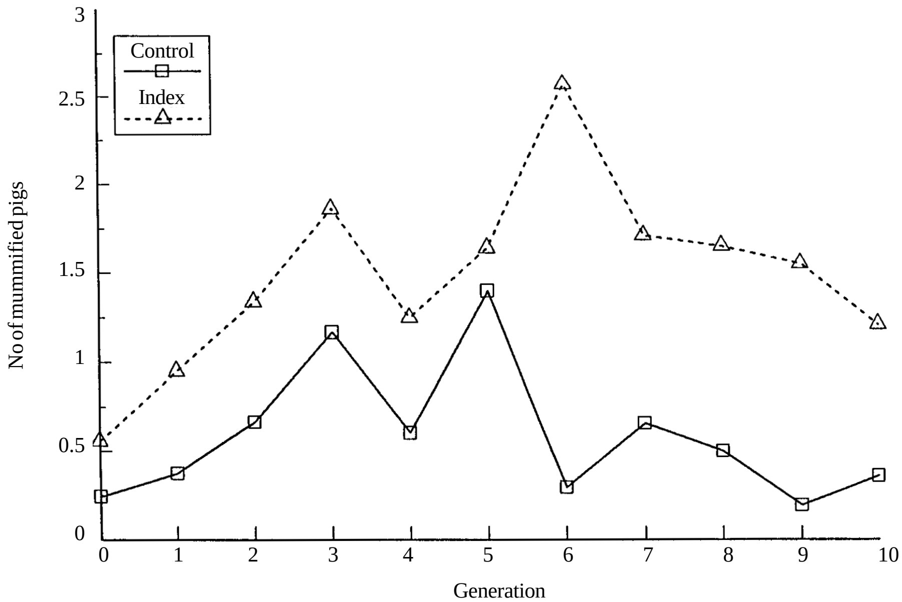

Figure 3. Number of mummified pigs at birth

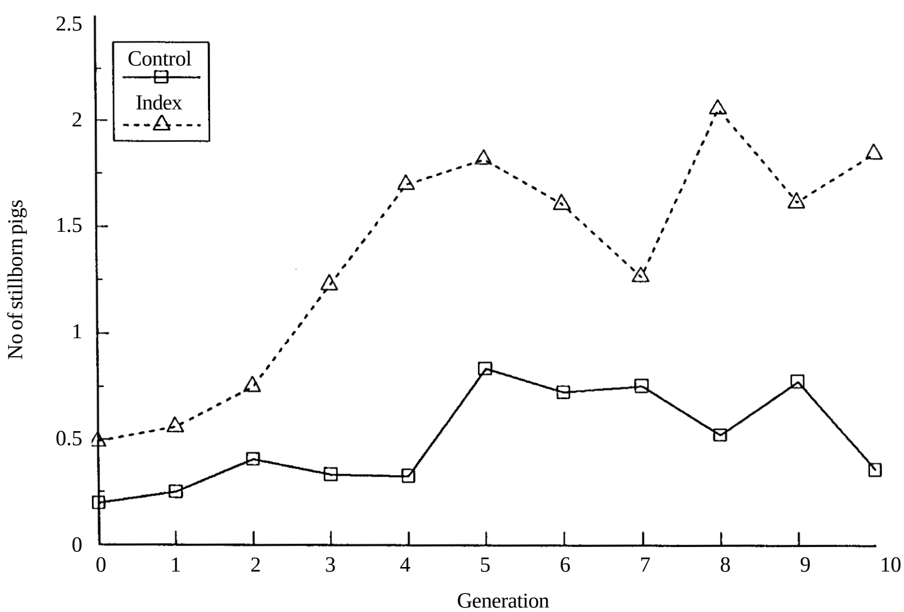

Figure 4. Number of stillborn pigs at birth

response in number of fully formed pigs was .11 $\pm$ .05 pigs at birth per generation and the average in number of pigs born alive was only .002$\pm$.049 pigs per generation.

Index line gilts had significantly more mummified pigs at birth than controls (Figure 3), and the difference increased with generation number. The difference was approximately one more mummified pig per litter for Index line gilts in the latter generations. This explains approximately half of the decrease in response in number of fully formed pigs at birth compared to the response in number of fetuses at 50 days of gestation. The remainder of the loss was due to fetuses that died after 50 days of gestation and were reabsorbed so they were not found as a mummy. The incidence of this loss also increased during the experiment.

The number of stillborn pigs at birth increased significantly with generation number (Figure 4). The increase in number of fully formed pigs was offset by the increase in stillborn pigs so that little change in number born alive occurred.

Generation 11. Of the 164 Index gilts that were selected at 56 days of age, 130 were mated and 119 farrowed a litter, and 111 of 121 Control gilts were mated and 97 of these farrowed a litter. The percentage of gilts that mated and that farrowed was not significantly affected by either genetic line or gilt development diet.

There were no line x diet interactions on any litter traits measured at birth or weaning, nor were diet effects important ($P > .20$) but line differences were significant. Therefore, results in Table 1 are means for the lines, averaged across diets.

Index gilts had litters with 2.2 more ($P < .01$) fully formed pigs at birth than Control gilts, and 1.2 more ($P < .01$) pigs born alive. Because there were more pigs per litter, Index line gilts had heavier (2.9 lbs, $P < .05$) litters at birth, even though average weight of the pigs was less. Gilts of the two lines did not differ in weight of litter weaned after adjustment for numbers nursed by the gilt.

Discussion. The index was designed to place optimum weight on the component traits of litter size, ovulation rate and embryonic survival, so maximum response in litter size could be achieved. Expected rate of response was further enhanced by the method of measuring the traits during gestation. This permitted all gilts to be measured each generation so the selection rate for dams of boars was 15 in 160 compared to 15 in 45 that could have been achieved from direct selection for litter size at birth. So the net effect of the selection method used was more rapid expected response in litter size due jointly to greater selection differentials and opti-

Table 1. Mean litter sizes and weights for Index and Control gilts in Generation 11[a]

	Farrowing				Weaning	
Line	*n*	NFF	NBA	LBW, lb	*n*	LWW, lb[b]
Index	119	11.7**	10.1**	27.6*	116	113.0
Control	97	9.5	8.9**	24.7	95	114.9

* Lines differ, P < .05.
** Lines differ, P < .01.
[a] NFF = number of fully formed pigs at birth, NBA = number born alive, LBW = litter birth weight, and LWW = litter weaning weight
[b] Adjusted for number nursed.

mum weighting on the component traits in the index.

The response in litter size at 50 days of gestation was approximately twice what could be expected from direct selection for litter size at birth in an experiment of similar size. Therefore, the index method was very effective in changing this trait. The expectation from calculations made before the experiment began was that selection for the index would cause a rapid increase in ovulation and that there would be some decrease in embryonic survival rate, but that the net effect would be a substantial increase in litter size. The observed responses at 50 days of gestation agreed very well with these expectations.

When the experiment was started, it generally was believed that most of the embryonic loss occurred during the first 30 days of gestation and that the relationship between litter size at 50 days of gestation and litter size at term would be very high. However, there was substantial fetal death after 50 d of gestation in Index line gilts. Some of this death loss was due to the laparotomy procedure because Control gilts that had the laparotomy consistently had fewer fully formed pigs at birth (average approximately .7 pigs less) and more mummified pigs at birth (average approximately .3)

Therefore, the surgical procedure itself was causing some of the loss after 50 days of gestation. Because in later generations litter size at 50 days of gestation in the Index line was substantially greater than in the Control, it is possible that laparotomy caused more losses in Index line gilts than in Control gilts. However, it is also possible that fetal losses after 50 days of gestation were substantially greater in gilts with large litters because uterine capacity after 50 days of gestation was the limiting component in litter size at birth. If this is the case, the increase in litter size at 50 days of gestation would be partially offset by fetal losses, many of which would be found as mummified piglets at birth. Partitioning these variables as causes of fetal losses after 50 days of gestation required measurements of litter size without laparotomy in random samples of gilts from each line, which was done in generation 11.

The increase in number of stillbirths in litters by Index line gilts is difficult to explain. These pigs were fully formed and normal in size and likely died during parturition. We do not know whether stillborn pigs were normally born after a mummified piglet was expelled. However, Dr. Phil Dzuik, University of Illinois (personal communication) has observed that a pig born after a mummified pig is often stillborn. The reason, he speculated, was that the uterus is constricted at the location of a mummified pig and the length of time for the birthing process is delayed for the next live pig passing through this area, and this delay could cause its death.

The generation 11 experiment confirmed that litter size increased from the index selection. When no laparotomy was performed and a random sample of gilts was used, the difference in number of fully formed pigs was 2.2 pigs, compared to an estimated difference of 1.1 pigs at generation 10. Further, when no laparotomy was done, lines differed by 1.2 pigs born alive. Therefore, we conclude that this index selection did increase litter size at birth, that the laparotomy procedure was more traumatic to Index gilts with large litters than Control gilts, and that fetal losses after 50 days of gestation are greater in Index line gilts than Controls. The last point follows from the fact that lines differed by 3.2 fetuses at 50 days of gestation, of which 2.2 was observed as a fully formed pig and 1.2 as a live pig in the generation 11 sample. Because diet did not affect the reproductive traits and there was not a diet x line interaction, we conclude the increased reproductive potential of the Index line gilts cannot be realized by feeding diets with more protein, vitamins and minerals than those recommended by NRC.

We conclude that the index selection method used in this experiment can be used to enhance rate of response above that expected from normal litter size selection. However, to enhance response in litter size at birth the index should be based on ovulation rate and litter size at term. It is not recommended that selection at 50 days of gestation, as used in this experiment, be applied by the industry. Rather, procedures should be developed to jointly select for ovulation rate and uterine capacity to term to effectively utilize these methods.

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