Blueprint for Selecting Parasite Resistant Sheep: A Shepherd's Perspective

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Introduction:
The concept of selecting parasite resistant sheep is simple: consistently select the animals with the best resistance. Putting the concept into practice, however, can be more challenging. This paper will share some of the lessons learned over the last 10 years through several North Central Sustainable Agriculture Research and Education (NC SARE) grants and on-farm experience. A list of the SARE grants and the breeders involved is included at the end of this blueprint.

Background:
Gastrointestinal nematodes (GIN) are one of the most limiting factors to profitable production for shepherds raising sheep on pasture. GIN are often referred to as worms, internal parasites or just parasites, but the principal GIN of concern in Ohio and much of the country is *Haemonchus contortus* or barber pole worm.

The most obvious GIN cost to producers is through deaths of lambs and ewes. Probably more loss occurs in lambs because of anemia, reduced appetite, slower growth, delays in reaching market weight, and less immunity to other diseases. In ewes, a parasite burden can result in decreased fertility, poor wool quality and lower milk production resulting in unthrifty lambs or pre-weaning mortality. GIN have developed resistance to available dewormers in most flocks in temperate and semi-tropical regions of the U.S. and other sheep producing regions of the world. Identifying and selecting animals, especially sires, who have genetic resistance to GIN, and the ability to transmit that resistance to their offspring, is one option for reducing economic losses related to parasitism.

Resistance:
Resistance to parasites is an immune response. Hair sheep breeds seem to develop immunity earlier (3-4 months in our flocks) compared to most wool sheep (5-7 months). Some sheep appear to have an innate or early resistance. This was reported by one of our advisors, Dr. Charles Parker, at the Ohio Agricultural Research and Development Center in Wooster Ohio in the 1980s. Innate resistance is what the lamb is born with, while acquired resistance is the result of the immune response being stimulated after being exposed to parasites. Lambs with innate resistance appear to have a lower FEC at an early age, before their acquired resistance has developed. These traits appear to be genetically related but separate traits. It's uncertain whether all sheep breeds express innate resistance, but it has been observed in some Katahdins, other hair sheep and Florida Natives.

Another component to resistance is the ability of some ewes to resist parasites following lambing and during lactation (the periparturient period). Most of the research has focused on identifying GIN resistance in lambs. Our on-farm research has also shown significant differences in fecal egg counts (FEC) among ewes during the periparturient period in our Katahdin flocks. Preliminary analysis of our data suggests that, although favorably correlated, resistance in ewes may be different from resistance as a lamb. In our flocks, periparturient resistance appears to be heritable from dam to daughter. Selecting ewes that are more resistant will decrease the numbers of parasite eggs shed on a pasture during lactation, which translates to reduced pasture contamination for the lambs. Parasite resistant ewes should also produce more milk and do a better job of maintaining condition during lactation than a ewe with a high parasite load.

Resistance is not complete; even resistant sheep will have some parasites, but they will have lower levels of parasites and lower fecal egg counts (FEC) than non-resistant animals when exposed to similar levels of worm larvae on pastures. Resilient sheep, on the other hand, can tolerate higher numbers of parasites without showing anemia or significant production loss. They can have relatively high FEC (and continue to contaminate pastures) without showing signs of anemia.

There are wide variations in the level of resistance among sheep in an unselected flock. Roughly 20% of the sheep in a flock are responsible for depositing 80% of the parasite eggs on a pasture. In general, hair breeds of sheep have more individuals with resistance to parasites than wool breeds. However, regardless of the breed, there are individual animals in every flock that will be more susceptible and more resistant to parasites. Identifying these individuals allows us to make selection and culling decisions.

Heritability:
Research has shown that resistance to parasites is one of the most heritable production traits. Heritability estimates range from 20-25% in wool breeds, while in hair breeds estimates range from 40-50%. As a comparison, heritability estimates for prolificacy are about 10% and post weaning (120 day) weights are 20%. This means that a good portion of the differences we see in parasite resistance among sheep are heritable and can be selected for. These genetic differences are cumulative and permanent.

It is generally accepted that parasite resistance is inherited on multiple genes. The best way to improve the resistance in our flocks is to increase the frequency of genes for resistance. We have found that animals with multiple generations of resistance more consistently pass that trait on to their offspring.

Approaches:
There are two basic approaches to selection for parasite resistance: selecting within an established gene pool, and the introgression of known parasite resistance genes into a flock. Most of our work and experience has been focused on selection within-flock or within an established gene pool, and mostly with Katahdins. This approach may be slower initially for producers starting with no pre-identified resistant animals, but it will maintain other qualities of the base flock and may be the best approach for many flocks. In our last SARE grant (FNC10-794) we observed that the introgression of parasite resistance genes from breeds with high levels of parasite resistance (i.e., Katahdin or Florida Native) also has merit. Introgression of proven genetics can allow faster progress for some producers, especially those with less resistant breeds, since the sires used in the

first generation should already have documented resistance. Both of these approaches still require identifying parasite resistant individuals and continued selection to be effective.

Techniques for GIN Management and selection:
There are several ways of identifying animals with more or less resistance to parasites, as shown in the table below. **Note: the success of all these techniques requires both a parasite challenge to detect differences in individual animals and accurate records.**

Method	Range	Advantages	Disadvantages
Deworming History	Yes or No	Easy	Least accurate. Limited ability to differentiate inferior and superior animals. Very subjective
Body Condition Score (BCS)	1 – 5	Somewhat more accurate than deworming history Easy to perform	Could select against highly productive animals Not specific for identifying GIN since other diseases can reduce BCS
FAMACHA	1 – 5	More accurate than BCS Easy to perform	Also selects for resilience Does not necessarily reduce pasture contamination Training highly recommended.
FEC	0 – 25,000+	Most accurate Large population variance = fastest improvement Selects for resistance rather than resilience Best way to identify resistant animals	Most expensive Labor intensive

Fecal egg counts are the most accurate way to identify potentially resistant animals, but are labor intensive and/or expensive. More information about using FEC is given at the end of this article. FAMACHA is a method of estimating parasite burden based on the level of anemia (a sign of infection with *Haemonchus contortus*), by evaluating the color of the mucosa of the lower eyelid. This method is relatively easy, but can also select for animals that are resilient, or able to tolerate heavier parasite loads. This technique does not necessarily lead to lower levels of pasture contamination, thus continuing to expose susceptible animals to parasite larvae. Body condition scoring is also easy, but has not proven to be effective in identifying parasite burdens in our flocks, especially in lambs. Without good production records, using body condition score can be misleading and, in ewes, can inadvertently select against the most productive or hard working animals. Deworming history is useful in combination with FEC, FAMACHA or body condition scoring, but of little value when used alone, unless 30-50% of the animals in the flock require deworming. If none of the flock requires deworming it's impossible to tell if the animals have had adequate exposure to parasite larvae to see differences.

We have found FEC to be the best technique to identify resistant animals in our flocks and this is the technique we use and recommend.

Principles of Selection:
Parasite resistance can only be measured by comparing adequate numbers of animals at the same stage of production, in a common environment and in the presence of a parasite challenge. There are numerous factors that influence FEC. Simply comparing the FEC of two animals won't give you meaningful information. Below are some of the influences we have seen in our flocks. Understanding the effect each of these factors has on FEC will allow you to more accurately compare animals and make appropriate decisions.

Stage of Production:
Animals being compared must be in the same stage of production. It isn't possible to compare lactating ewes and dry ewes, or ewes and lambs, or even three month and seven month old lambs. Most mature animals (i.e., rams and dry ewes) will have low FEC. Lambs and lactating ewes are the most susceptible to GIN and will usually have higher FEC. Very young lambs are more susceptible to parasites than older, heavier lambs.

Environment:
Most sheep will have low FEC without adequate exposure to parasites. This includes sheep grazing clean pastures, hayfields or annuals, or those kept in the barn. Time of year has a significant effect on FEC. Pasture contamination (and FEC) increases, often quickly, over the summer. In Ohio, lambs in May will typically be exposed to less pasture contamination than lambs in July or August. Most animals, even lambs, tend to have low FECs during the winter when parasites tend to be dormant or hypobiotic.

Good quality pasture and/or supplemental feed help to keep FEC lower, while animals that are nutritionally challenged (triplets, twins raised by yearling dams, lambs on poor quality pasture, etc.) are more susceptible to parasites and have higher FEC. So, lambs receiving creep feed can't be compared equally to lambs that don't. Triplets can't be compared equally to singles, etc. Stresses such as lactation, weaning, transportation, and relocation will often cause an increase in FEC. Stocking density is also important; the more sheep on a pasture, the sooner the pasture will become contaminated.

Challenge:
In order to see differences among a group of lambs or ewes, there must be a parasite challenge. Otherwise, you won't know if a low FEC is due to resistance or lack of exposure to parasite larvae, good nutrition, etc. **A group average FEC of at least 500 epg is required and 1000 epg is even better.** An adequate number of animals is essential. Because of the wide variation in FEC, 10-15 animals are necessary, and more is better. Don't include individual animals dewormed less than 30 days before the FEC is performed; their lower FEC after deworming will make them appear resistant.

Identify resistant animals
The procedure we use is to perform FEC on an entire group of animals at the same stage of production. That could be ewes during lactation, or lambs in the summer. Unfortunately, there is not a correction factor for ewes raising triplets versus ewes raising singles, or lambs raised as triplets versus lambs raised as twins, but this should be taken into consideration when analyzing results. Detailed instructions for collecting and submitting FEC are included at the end of this article. In general, animals with lower FEC are preferred. BUT, as mentioned above, most (50%-80%) of the differences seen among animals are the result of environment or management. In order to make progress in selection, we need to objectively identify those animals that possess true genetic resistance regardless of management and environmental influences.

Determine the average FEC for the group of animals you are comparing. It's best to select an animal with a FEC below the group average, **assuming there was a parasite challenge of at least 500 epg**. Because a FEC is simply a snapshot in time, it is best to perform a second test four to six weeks after the first. The best animals will be low at both collections. It is also acceptable to have only the second FEC low, as long as the first FEC isn't much above the group average.

Sire selection:
A ram contributes 50% of his genetics to his lambs. We have repeatedly found on our farms that a ram with below average FEC as a lamb will sire lambs whose group average FEC is lower. That doesn't mean that every single lamb will be low, but the average for the group will be lower.

When selecting a mature ram, look at the FEC on his offspring and on his own records when he was a lamb. It won't do much good to check FEC on adult rams, since adult animals are expected to have low FEC. Accuracy will be increased if you can compare progeny from at least two sires. The lambs must be of similar age and managed the same, and you'll need to compare an adequate number of lambs (at least 10-15 per sire is best). Then, calculate the average FEC of all the lambs, as well as the average FEC of the progeny for each sire. Choose the sire with the lowest average progeny FEC, or one of his sons with a below average individual FEC. Note that multiple FEC over the summer, multiple years of data and multiple generations increase accuracy.

Using Ratios:
It's difficult to compare animals across flocks, and using different laboratories or methods of determining FEC makes it even more difficult. Techniques, and therefore results, vary slightly between labs, so comparing raw numbers can be misleading. Just knowing that a lamb has a FEC of 600 epg tells you little unless you know the average of all his contemporaries. On a farm where the average FEC is 500 epg, the lamb with 600 epg would be just above average, while on a farm with an average FEC of 1200 epg, the lamb with a count of 600 epg would show more resistance. The same thing applies to comparing animals in different years on the same farm, as parasite conditions change from year to year. To adjust for this, we often use a ratio (the individual animal's FEC divided by the flock average), rather than a raw number when comparing animals. A

result of 1.0 would be average, greater than 1.0 (i.e., 1.5) would show less resistance and anything below 1.0 (i.e., 0.5) would show more resistance.

Estimated Breeding Values (EBV):
The most accurate indicator of parasite resistance available to U.S. Katahdin and Polypay breeders is the FEC Expected Breeding Value (EBV) available through the National Sheep Improvement Program (NSIP). EBVs greatly increase the accuracy of selection within a farm and also allow producers to compare performance between farms. The mathematics behind EBVs factors out the environmental component from the genetic component. As of 2013, this tool is being used by a number of Katahdin breeders and some Polypay flocks. There are requirements for the data used in the NSIP evaluation. The flock needs to have a sufficient level of parasites (the group average for the lambs must be more than 500 epg), and the flock must use at least two sires per farm with data submitted on 10 or more lambs per sire.

EBVs are most easily used as a relative tool. The FEC EBV (given as a percentage) gives an estimate of the genetic potential for parasite resistance. A value of zero is considered average for the breed, and animals with a negative (or positive) number are considered to be below (or above) the breed average. For example, an animal with a FEC EBV of -50% is predicted to have a fecal egg count of 50% below the breed average, while a +50% is predicted to have a FEC 50% above the breed average. Note: it is not possible to compare FEC EBVs between breeds. FEC EBVs take into account not only the individual lamb's degree of resistance, but also factor in the resistance of its siblings, parents and grandparents, and allow comparisons between flocks. This is made possible by a centralized data analysis service, the same technology used by the beef and dairy industries to improve production traits.

The most accurate way to use EBVs to identify a parasite resistant animal is to find one with negative FEC EBVs. Zero is considered average, and the lower the number the more resistant the animal is expected to be. The accuracy estimate for the EBV is important, though. It's possible for an animal to have FEC EBVs without having submitted any data on that individual animal (or farm), if there are relatives in the system. If no accuracy value is given, the FEC EBVs are based on pedigree, or relatives' performance. As with predicting accuracy for other traits, the higher the accuracy number the more 'proven' or certain the number is. While low FEC EBVs with high accuracy are the ideal, an animal with low FEC EBVs with low accuracy is still a better risk than an animal with no data.

Cull susceptible animals
Culling the animals under common management that consistently have the highest parasite challenge will help reduce the level of pasture contamination. Sometimes, though, these animals are your best for other traits. If so, you may choose to keep them but will want to mate them to your most resistant animals. While culling susceptible animals will help with parasite management by removing problem animals, it's not enough by itself to help improve the parasite resistance of a flock. If you participate in

NSIP and have FEC EBVs, you might consider culling animals with positive FEC EBV values that are also above the average for your flock.

Going forward:
Progress will be fastest if you can accurately identify and use rams and ewes with superior resistance for breeding, while at the same time culling the animals with inferior resistance. It is the recombination of genes for parasite resistance from your resistant sires and dams that will provide the next level of resistance. The more generations of parasite resistant animals in the pedigree, the more likely the offspring will be resistant. So, whenever possible, use a ram that has at least average FEC as a lamb (as outlined above). This will strengthen your data and allow faster progress.

Working with other flocks to share rams and evaluate their offspring in different areas, different systems, etc. will also allow faster and more accurate progress. You will need to have sources for new genetics to avoid excessive inbreeding. The best strategy is to join a group of like-minded breeders who are willing to invest the time and effort required to collect FEC data. Remember that nearly every flock has some individual animals with better than average parasite resistance. Work with other producers to identify and use those animals when possible. If your flock is large enough and/or you have several years of solid data, it's acceptable to introduce a ram without FEC data occasionally, while also using at least one known sire for comparison.

Line breeding or close breeding may be an option as you begin to identify and strengthen parasite resistant lines. But, there are risks involved with inbreeding and you have to be willing to cull undesirable animals. The SID Sheep Production Handbook has an excellent section on breeding and selection. The same principles mentioned above apply: you must have a challenge to see differences in animals, and you must have a large enough group of animals under common management to see differences between sires.

Pasture Management:
One of the biggest challenges we have found is pasture management. In order to see differences among animals there must be sufficient numbers of parasites on the pasture to provide a challenge. An **FEC average above at least 500 epg is essential** to insure that all sheep are challenged and that a low FEC really means something. This requires careful monitoring, such as weekly FAMACHA checks, especially during times of high pasture contamination, high rainfall and warm temperatures. Clean pastures are wonderful for lamb production, and are one of our goals as producers, but we still need an adequate challenge to get good data on parasite resistance. **Caution:** having a large number of parasite larvae on the pasture early in the summer can quickly become dangerous, even for resistant animals, later in the year. Even if there are no animal deaths, production will be decreased. It's important to remember that parasite resistance is not absolute and even resistant animals can be overcome with a severe challenge. This is especially true of the most vulnerable groups: lambs and lactating ewes.

We strongly discourage making parasite resistance your only selection criteria (single trait selection). Most of us try to balance parasite resistance with production as measured by total pounds of lamb weaned per ewe lambing each year. Every year there will be trade offs. One of our mentors has suggested we try to moving one trait forward while avoiding going backward on any of our other key traits at each breeding.

Probably the most important component of selecting for resistance is perseverance on the part of the shepherd. Correctly identifying resistant animals and producing resistant offspring while maintaining or improving other important production traits, can take three to five years and even longer. Continue to retain low FEC lambs that were exposed to a significant challenge and cull those with high FEC. Don't be discouraged by the occasional small step back ward or by the occasional summer of high parasite load; focus on the long term. Incorporating FEC into your selection program will result in improved parasite resistance in your flock over time.

Recommendations for FEC collection and analysis

Fecal egg counts (FEC) are estimates of the number of eggs being shed in a gram of feces. They are performed using a microscope to examine a mixture of a specific amount of fecal material with a specific amount of flotation solution in a special chambered slide (McMasters). They provide the best idea of the level of parasites in a sheep.

FEC have several uses. They can be used before and after deworming to estimate the efficacy of an anthelmintic (dewormer). They can give an idea of the level of pasture contamination. They can be used to get an idea of how heavily parasitized an animals is, although this can be misleading. FEC measure the number of eggs being shed, but early in the infection, it's possible for an animal to have a large number of young adult worms that are sucking blood or damaging tissues but not laying eggs yet. A combination of FAMACHA and FEC will help in that case. Finally, FEC can be used to identify animals that have higher or lower counts than the flock average as part of a selection program.

Whether selecting replacement animals or new purchases, a parasite challenge is essential for a valid comparison of animals. There are two reliable times during an animal's life to identify parasite resistance and both require exposure to parasites: as a lamb and during lactation for ewes. The best time to test varies from year to year and flock to flock depending on lambing dates, age of lambs, weather, etc.

The model we use for lambs, described below, is the one used for the FEC EBV developed by the National Sheep Improvement Program. The first sample is collected at the time you start deworming (around weaning in many flocks). This provides an estimate of innate resistance. Then, a second collection is done four to six weeks later at a time of maximum challenge, which estimates acquired resistance. If a significant number of lambs need to be dewormed at the time of first collection, it's important to deworm all the lambs if you plan to do a second collection so they will all have had a similar challenge. For ewes we have found that FEC at about 30 days post lambing gives a good idea of a ewe's parasite resistance during the periparturient period.

The range in FEC can be huge – we've seen counts range from 0 epg to 15,000 epg or more in the same group of lambs. Therefore, you will need to compare adequate numbers of lambs. It is recommended that 15 lambs per sire be compared, with 10 lambs per sire being the minimum. In order to ensure there is an adequate challenge, the **average** FEC of all the lambs in the group needs to be at least 500 epg, and 1000 epg is better. In an unselected flock, this is usually about the time that 5-10% of the lambs require deworming based on FAMACHA scores of 3 or higher.

You'll need to collect fecal samples from a representative group of animals at the same stage of production and managed together in a single group. Don't compare lactating ewes and dry ewes, or ewes and lambs, or even three month and seven month old lambs. Then, collect samples from a group that includes some of the largest, middle and smallest animals, or exclude the top and bottom 10% and just collect from the middle range. If you have both ram and ewe lambs in the group, try to collect samples from an equal number of each sex. The idea is to get a representative sample that reflects the average of the whole group.

Before you collect any samples, know where you're going to send the samples for analysis. Some veterinary clinics perform quantitative FEC, and some vet colleges will do them. Be sure to request a **quantitative** FEC (McMaster), not a simple float. The quantitative FEC will be expressed as the number of eggs in a gram of feces, reported as *XX* epg, while the floatation simply tells you if eggs are seen and is often reported as +, ++ or +++. Be sure to ask when samples can be received by the lab (i.e., some labs don't want samples delivered on Friday or before a holiday), and time your collection and mailing accordingly.

If you're doing FEC on a random group of animals to get an estimate of the parasite challenge in the flock, knowing which animal a sample came from probably isn't important. But if you're doing FEC as part of a selective breeding program, correct identification of the individual animal is essential.

To collect a sample, you will need exam gloves, sealable plastic sandwich bags, and something to label the bags (a Sharpie pen works well). Collect samples directly from the rectum of the animal, unless you can catch the sample mid-air and at the same time make a positive ID of the animal. It is not recommended to collect samples from the ground due to potential contamination and risk of incorrect identification. You will need about 4 grams of fecal material, and we like to collect a bit more if possible. That's about one heaping tablespoon, or half a dozen large pellets or 12-20 small lamb pellets. Write the animal's ID number on the outside of the bag and express as much air as possible before sealing. Keep the samples cool as you're collecting by placing them in a cooler with ice, but don't allow them to freeze. (Keep a layer of newspaper between an icepack and the samples.)

Once you have the samples collected, they need to be refrigerated until they reach the laboratory. Do not allow the samples to remain at room temperature (the eggs will hatch) or freeze (the eggs may rupture). We have found the best way to ship samples is in an insulated box with an ice pack on top, separated by a layer of newspaper. If it's really hot, use two icepacks, one on top and one on the bottom. Depending on the weather, the samples should be shipped 2nd day (cool weather) or next day (hot weather). The lab you're working with will give you specific directions. It's always best to ask.

When you get your results back, they will typically include the animal ID number and the number of eggs per gram (epg) of feces. Counts can range from 0 (sometimes reported as "no eggs seen") to 25,000 epg or higher. This count will reflect only the number of trichostrongyle eggs seen (several of the common GIN have eggs that all look alike). The count will not include coccidia or tapeworms or other types of parasite eggs, although if the count is very high there will sometimes be a comment to that effect. Calculate the average for the group. As we've said before, in order to see differences among animals you must have a challenge, with a group average of at least 500 epg. However, it's possible to have such a high average that the immune response of all the lambs is overwhelmed and differences are again hard to detect. Once you have the average for the group, you can use the results to identify animals that are above or below the flock average. Animals that are consistently above or below the average on more than one collection are good candidates for culling or retaining, respectively.

It's important to note that a single FEC from a single animal will tell you little or nothing. Without a comparison to other animals at the same stage of production or same age, and under the same management, you don't know if a count is low, average or high. Even a single FEC on a group of animals is only a snapshot in time. FEC are not static. While often FEC tend to increase over the summer, we have seen in our flocks that counts fluctuate from week to week on individual animals throughout the summer as they develop an immune response to GIN. Unless you plan to collect samples every couple weeks (which is not necessary and not recommended), you probably won't notice these fluctuations. The timing of sample collection relative to the development of the immune response will have an effect on how resistant an animal appears though. Collection of a second set of samples four to six weeks later helps smooth out the results, and is probably a feasible approach for most flocks.

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