Relay Cropping in the Willamette Valley
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Introduction

Most dairies in the Willamette Valley grow field corn for harvest as silage. Dairy farmers usually plant corn in late April or May; some may plant in June if the spring weather is wet and fields are not yet tillable.

Dairy farmers usually apply manure from storage ponds and solid stacking facilities just prior to working ground for corn planting, so soil nutrients on dairy fields usually are plentiful.

Shabtia Bittman of the Research Station in Agassiz, British Columbia introduced the management practice of relay cropping to dairy farmers in Canada. Dairy workers in Washington and Oregon observed his results and introduced this practice in the Pacific Northwest. They planted Italian ryegrass, an annual ryegrass variety, between 30-inch corn rows, using a grain drill, when the corn was about 3-4 weeks old.

The idea is simple: plant a grass crop to grow with the corn so that when the corn is harvested, the grass is already germinated. It then will provide winter cover and will scavenge nutrients that are left over after the corn is harvested.

The relay crop practice is similar to double planting, in which annual ryegrass is planted immediately following corn. With relay cropping, however, the crop is already 20-30 days ahead of the growth cycle. This practice also eliminates the need for planting in the fall, when rain can make field tillage difficult.

This publication describes the methodology and results of a 2-year field study of relay cropping involving annual ryegrass planted into field corn on dairies in the Willamette Valley of Oregon. The study measured soil nitrate-N, potassium, and phosphorus levels in fall and spring as well as nitrogen, phosphorus, and potassium uptake and crop yield. The objective was to determine the effect of relay cropping on the presence of soil nutrients following the winter rainy season.

Planting procedure

Seed selection was based on two criteria: cost and palatability. Usually a tetraploid variety or the more common Gulf variety of ryegrass was planted.

For the first year (1996–97), eight fields on eight different dairy farms were planted. Seed was drilled between the corn rows at a rate of 20–25 pounds per acre. The planting depth was 1 inch. Planting dates ranged from June 17 to July 11, 1996. The corn varied from just sprouting to 12 inches tall at ryegrass planting time.

For the second year (1997–98), 11 fields on 11 different dairy farms were planted. Seed was broadcast between the corn rows at a rate of 20–25 pounds per acre using a four-wheel-drive all-terrain vehicle with a small broadcast spreader. Seeds were not cultivated or tilled into the soil. Planting dates ranged from June 4 to June 24, 1997. The corn ranged from just sprouted to 18 inches tall when the ryegrass was planted.

Herbicides

Dairy farmers used one or a combination of these herbicides for weed control: Frontier, Atrazine, Dual, and Eradicane. Some herbicides were used preplant, some were used postemergence, and none were used after the relay crop was planted.

Soil and plant testing

All relay crop cornfields were soil sampled (at the first foot) as soon as possible after corn harvest in the fall. One objective was to determine fall soil nutrient levels following corn. Especially for nitrate-N, this serves as a report card for soluble nitrogen that could be lost to denitrification or leaching.

Relay crop fields also were sampled in the spring, usually soon after the relay crop was harvested or cultivated into the soil as green manure.

Nutrient uptake (NPK) was determined by lab analysis of fresh plant tissue obtained by field grab sampling.

Crop yield was measured by visual observation and estimates (1997) and by weighing a known area for more accurate yield determination (1998).
Results and discussion

Soil nitrate-N

Nitrate-N is a terminal nitrogen form after undergoing oxidation in the soil. This form of nitrogen carries a negative charge. Since the soil is slightly negatively charged, there is no attraction between nitrate and soil particles. This means that nitrate can be easily carried by water past the root zone in the form of leaching. In flooded soils, bacteria may strip the nitrogen away from the nitrate in order to have oxygen for oxidative purposes (denitrification).

Nitrate-N measurement, especially in the fall after the summer growing season, tells us something about how much nitrate-N is left over in the top foot of soil. Farmers should try to minimize this number so as to avoid leaching or denitrification during the winter.

The objectives of nitrate management are simple:
- Increase crop uptake by increasing crop yield and quality (higher crude protein content).
- Reduce manure application, commercial fertilizer application, or possibly tillage that puts oxygen into the soil.

Figure 1 shows the fall and spring nitrate-N concentrations in the soil at the top foot for all fields in this study.

The average value for each year is:
1996–1997: 149 pounds fall
41 pounds spring
1997–1998: 228 pounds fall
38 pounds spring

Using a threshold value of 100 pounds of nitrate-N at the end of the growing season, then for both years excess nitrate-N existed in the cornfields on average. For both years, 13 out of 19 cornfields had more than 100 pounds nitrate-N/acre in the fall.

In asking why, one might consider the fact that nitrate-N is a terminal form of nitrogen, and thus it had to undergo many chemical transformations to get to its fully oxidized form of nitrate. Its source cannot be known without rigorous examination in a controlled environment. Yet one can assume that levels over 100 pounds/acre are the result of many transformations, and that crop uptake did not extract these molecules at the rate at which they were made.

The spring number shows that most of the soil nitrate is gone regardless of the amount in the top foot of soil in the fall. The planting of a relay or double crop to capture this loss was one of the primary objectives of this project.

Figure 1.—Soil nitrate-N in the top foot of soil (fall and spring).
Soil phosphorus (P)

Figure 2 shows plant-available soil test phosphorus in the fall and spring in all study fields. According to these data, little difference exists between fall and spring.

The majority of soil P is organic. Almost all manure P is organic or undigested mineral P that leaves the cow in the feces. Biological mineralization of these soil and manure P molecules must occur before plant-available (soil test) P can be used.

The average value for each year is:

1996–1997: 104 ppm fall
91 ppm spring
1997–1998: 118 ppm fall
105 ppm spring

Using a threshold value of 100 ppm as excessive, the average dairy field in this project is at that level.

Since P exists primarily in the top few inches of soil, the opportunity for soil loss is through soil movement off the field, usually as erosion. One objective of planting a relay or double crop is to provide plant biomass that will help stabilize soil particles and prevent erosion, as well as use some of this plant-available P.

Note: in all graphs, field 9 (1996–1997) and field 12 (1997–1998) are the averages of all fields for that year.
Soil potassium (K)

The final soil test is for potassium, a cation that is missing an electron in its outer valence shell; thus, it carries a positive charge. There are two other primary cations in the soil, calcium and magnesium. All of these cations are immobile once in soil, as they adhere to negatively charged organic matter and clay particles in what is called the cation exchange capacity.

Their concentration in the plant depends somewhat on the concentration in the soil. That is, if K is in high concentrations relative to Ca and Mg in the soil, then plants, especially grasses and legumes, also will have high concentrations of K.

Dairy manure contains K in its liquid fraction, as it is a metabolite of cation digestion in the dairy animal. Dietary cations usually are absorbed into the digestive system, and it is the responsibility of the kidney to remove them from blood should they significantly alter blood cation chemistry.

One would test for soil K as an indication of what might be expected to be taken up by plants. When rations are put together, feedstuffs containing higher than normal K concentrations must be diluted with other feeds having low K concentrations. The nutrition challenge is to avoid a cation imbalance; the manure challenge is to avoid urine containing high levels of K that end up in the liquid manure fraction.

The average value for potassium each year in this study was (see Figure 3):

1996–1997: 585 ppm fall
            458 ppm spring
1997–1998: 733 ppm fall
            622 ppm spring

The values listed are plant-available K. Liquid manure as applied to fields contains K in the plant-available form and does not need chemical transformation (mineralization) to convert it to plant-available form.

Using a threshold value of 800 ppm, the average dairy field was beneath that concentration. Spring values are lower, indicating some uptake by the relay crop. One objective of having a crop to scavenge available K is to keep its concentration more in balance with Ca and Mg.

Five fields of the 19 showed K levels above the threshold value of 800 ppm. A good management strategy for these fields would be to reduce liquid manure application and apply more manure solids. This recommendation, however, should be used in conjunction with knowledge of N and P concentrations.

![Figure 3.—Soil potassium (fall and spring).](image-url)
Pounds NPK uptake per acre

What is the performance of the relay crop in removing NPK from the soil? Here is the average value of nutrient uptake by the relay crop for both years:

1997: 139 pounds N
       12 pounds P
       116 pounds K

1998: 65 pounds N
       12 pounds P
       110 pounds K

The obvious difference between the 2 years is the amount of N uptake. In 1997, three fields showed more than 300 pounds/acre of N uptake, while the other four showed much less. But for the 1998 crop fields, none showed such a high level of plant uptake, and the differences among fields were not as great.

Comparing nitrate-N loss with uptake, the average results are:

1997: 108 pounds N lost from soil during winter
       139 pounds N taken up by the crop

1998: 190 pounds N lost from soil during winter
       65 pounds N taken up by the crop

The amount taken up by the crop represents nitrate-N that otherwise might have been lost over the winter through leaching and denitrification.

In 1997, crop uptake exceeded loss, but in 1998, crop uptake was only one-third of the loss. Keep in mind that these are average figures for the project each year. Individual fields varied significantly as indicated in Figure 4.

For 1997, four fields had little production and therefore little crop uptake. Three fields had productive fields, and crop uptake was accordingly high. For 1998, fields were more uniform in production, and the crop uptake graph shows less variation among fields.

Interestingly, only one field in 1998 showed more than 100 pounds of N uptake, whereas four fields (half of the project fields) in 1997 had at least 100 pounds of crop N uptake.

Nutrient crop uptake for any crop is a result of many variables; the two in this study that most influenced crop uptake were yield (tons) and crop concentrations of NPK.

Figure 4.—NPK uptake per acre.

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Dry matter yield

Figure 5 shows ryegrass crop yield expressed as tons of dry matter produced per acre. In 1997, yield was estimated, and in 1998, the yields were measured more accurately using multiple square foot cuttings and weighing fresh biomass production.

Interestingly, the average crop yield for both years is slightly less than 2 tons per acre. While there were wide yield fluctuations among fields in a given year and between years, the averages for each year were 1.9 tons of DM per acre.

One can place an economic value on this production. Our variable costs included seed costs of $8.00–$12.00/acre and planting costs of $12.00/acre (estimated). The land cost was fixed regardless of whether a crop was growing. Farmers did not irrigate this crop. In its early months of growth (July–September), the corn was irrigated, and the immature ryegrass plants utilized some of this water, albeit a small amount.

The 1.9 tons of dry matter per acre was worth $152.00 per acre @ $80.00/ton DM. Therefore, the return on investment was 700 percent, or about $7.00 for every $1 of variable cost investment. The optimal yield, which is yet to be determined, will drive the return higher.

The fate of this annual ryegrass was site-specific and largely depended on the dairy owner’s management program. About one-third of these fields were harvested for silage and fed to lactating cows. The above price of $80.00/ton DM would be a reasonable price for this type of silage ($18.00–$20.00/wet basis tons).

Heifers or sheep grazed another third of the fields. This practice is especially useful when the fields are too wet for mechanical harvest but can be grazed. The fields are tilled in preparation for another corn growing season, so excess animal wear is not a problem.

The final third of all fields were sprayed with herbicide, and the ryegrass was worked back into the soil as green manure. While this is useful from a soil ecology standpoint, ultimately nutrients are once more returning to the soil, although they are in an organic form. The objective of capturing residual nitrate has been accomplished, however. As green manure, the soil is fed with organic matter that improves soil tilth and ultimately becomes food for a crop in the years to come.

The relay crop program is versatile, then, in what ultimately happens to the crop. In most years, weather drives the decision of harvest strategy. If it is dry enough early in the spring, the grass is harvested as wilted biomass; it is placed in a silo, and the resulting silage provides a major portion of the lactating cow ration. Additionally, this early harvested grass is low enough in fiber and high enough in protein that it is largely digestible. No digestibility studies were done in this project, however.
Limiting factors
As with all farming studies, something about practical farming management techniques was learned. Here are some items that specifically address relay cropping:

1. Several different varieties of annual and biennial ryegrass were planted. None showed any particular benefit over another. Therefore, cost can be the driver for variety selection. If Gulf can be purchased inexpensively, then buy more and use heavier seeding rates per acre.

2. The seeding rates for both years, 20–25 pounds, were inadequate. A rate of 40 pounds/acre is suggested, especially if seed is broadcast.

3. Should one drill or broadcast? Drilling at the time of corn planting and then planting the corn seems to work well. As the corn grows over the row space (canopy), a broadcast program does not work well unless you will be cultivating the rows. No fields in this study were cultivated. Drilling takes more time, but the seed is placed into the soil instead of on top, and that is important (next point).

4. If there is a limiting factor in relay crop success, it is keeping immature ryegrass plants alive during the hot summer period from July through the first half of September. Plants at this stage have a root one-quarter to one-third of an inch long. Unless the irrigation cycle is timely (6 or 7 days), ryegrass plants that are broadcast will die. Those planted with a grain drill are better able to handle longer irrigation cycles because they are not at the surface and can reach moisture for a few more days after the surface dries out.

This one management practice alone made the difference between a highly productive field in the spring and a poorly yielding one. The importance of keeping these plants wet, almost like planting a lawn in your cornfield, cannot be overstated.

5. Herbicide control was a concern, but turned out to be a non-issue. By the time ryegrass was planted, the preplant herbicide had done its job, and little if any residual effect prohibited ryegrass from growing. Thus, preplant herbicides are not a concern if a relay crop of annual ryegrass is planted 20–30 days after corn is planted. However, once the relay crop is planted, a postemergence herbicide program should be planned to avoid damaging this immature grass. Farmers certainly cannot apply postemergence spray to remove excessive grass, such as quack or millet, and expect ryegrass to live. It will not.

6. In some fields, weeds did in fact overtake the crop. The weeds were primarily broadleaf, such as pigweed and lambsquarter. In other fields, millet was a huge problem. Some dairy owners chose to spray the millet and significantly reduced the stand of the relay crop. In other fields where preplant herbicides were effective well into the growing season, the relay crop grew nicely.

7. For dairy owners concerned with feed quality, the relay crop program works if they can get into a field for harvest early in the spring. Keep in mind that this crop has been in the ground for almost 11 months, and in April or May the grass can be quite mature (more fibers, less soluble components).

Nevertheless, if the feed quality is not sufficient for lactating cows, and if heifer or dry cow feed is not needed, the biomass can be tilled back into the soil for green manure. This extra tillage and possibly herbicide control does have a cost. The benefit, however, is that the crop has secured some residual nitrate as organic N, a stable form that must undergo mineralization before it is available for plant uptake or leaching loss.

Root mass
In this project, an interesting side study about relay cropping involved the root zone. One cubic foot of plant/soil was removed from two fields during April 1997, just prior to harvest, by the dairy owner.

Each cubic foot of soil was weighed. In both fields, the weight was 120–122 pounds. A cubic foot of dry soil (estimated) weighs 82 pounds, so these cubes were heavy with water. The soil was washed away, and then the root material was weighed.

At least 90 percent of the total root mass was in the top 4 inches of soil. The next 4 inches of soil (4–8 inch depth) had 5 percent, and the last 4 inches (8–12 inch depth) had less than 2 percent of the total root mass by weight.
When relay or double cropping is mentioned as a capturing crop for leftover nitrate, the nitrogen in the root biomass contributes to the total capture. Here are the NPK nutrient content of roots on a per-acre basis in this study:

N: 60 pounds/acre
P: 14 pounds/acre
K: 36 pounds/acre

These two cubic-foot extractions were made from fields 3 and 8 for the 1997 harvest period. These were two of the best yielding fields for the year.

The root NPK component as a percentage of the NPK in the above-ground plant biomass was:

N: 19 percent
P: 54 percent
K: 14 percent

Therefore, the total plant/root NPK uptake in these two high-yielding fields was:

N: 371 pounds/acre
P: 40 pounds/acre
K: 296 pounds/acre

For high-yielding fields of annual ryegrass, the root mass adds almost one-fifth more N scavenging and therefore represents an additional measure of total nitrate capture during winter.

Summary

1. Annual or biennial ryegrass can be planted in standing corn as a relay crop in late May or early June.
2. The seeds will germinate when exposed to moisture. However, the first limiting factor in a successful stand of this crop is subsequent water so that the young seeds survive. This means an irrigation cycle of about 7 or 8 days during July through August and possibly September, when ambient temperatures are highest and ryegrass plants are very small and susceptible to drying out. This point cannot be stressed enough.
3. A huge advantage of using this crop is the seed cost, usually 25 to 40 cents per pound. The only other variable costs are the operator's time and equipment for planting. There is no fertilizer or irrigation cost.
4. As much as 500 pounds of N can be taken out of the soil: 200 pounds in the corn crop and 300 pounds in the annual ryegrass crop. The potential of DM production per acre is:
   28 tons wet basis corn at 30 percent DM = 8.4 tons; 20 tons wet basis annual ryegrass at 21 percent DM = 4.2 tons. Potentially, then, there are 12.6 tons DM per acre.
5. Having ground cover reduces soil erosion. While we did not measure this loss, we can safely assume that having a cover crop will help stabilize the topsoil during heavy rainfall events.
6. Wintertime application of liquid manure is less likely to run off on fields where a relay crop is established. This crop serves as a buffer strip covering the entire field.
7. Stewardship is enhanced. A grass field consumes a greenhouse gas, carbon dioxide, and gives off oxygen as a by-product of its growth. This does not occur in an empty cornfield.
8. At least some nitrate-N leaching is avoided during the winter. Tracking nitrate-N is difficult in that it has several pathways; the most valuable one is entry into the relay crop that serves as digestible protein for animals.

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