HOW ARE COVER CROPS AFFECTING MY NUTRIENT LEVELS?
Understanding cover crop qualities and strategies for efficient nutrient management

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Making good cover crop choices first requires identifying a suite of services that the grower wishes to reap from the crop, then knowing which cover crops can provide those services, and cover crop management practices can enhance those services. Just as your cover crop choices will be influenced by the non-nutrient services you are looking for, they can be also influenced by how they affect nutrient levels. The effects of cover crops on nutrients should be understood for efficient and economical nutrient management. Understanding how different cover crops acquire nutrients gives a basis for understanding the effects they have on nutrients in the field.

A basic way to begin understanding this is to divide the most common cover crops into three to four groups that share common traits (chiefly by plant family), and also including general root structure and nutrient acquisition strategies. Grasses (fibrous root systems), legumes (taproot, nitrogen-fixing roots), and brassicas (taproot, non-mycorrhizal) constitute the majority of our cover crop choices with a few other exceptions (sunflowers, buckwheat, etc.). They can be used alone, or can be combined for a suite of complementary nutrient cycling services. Annual vs. perennial crop choices also influence how nutrients are cycled, through the depth of their root systems and the length of time that they allow soils to remain undisturbed.

Cover crops differ in the amount of carbon they return to soils as well, either through roots or aboveground growth. The timing of termination of cover crops heavily influences the rate of nutrient cycling (earlier termination increases the rate that nutrients in cover crop residues will become plant-available), and how much carbon is returned to soils (later terminations will return more carbon, but slow the return of plant-available nutrients to soils). When tillage is frequent in cropping systems, increases in soil organic matter from cover crops occur very slowly (a goal appropriate for a decade, rather than for a year), but as organic matter levels rise, soils should be expected to become more inherently fertile through multiple cascading positive changes in soil health.

The effects of legumes on soil nitrogen levels, and the levels of other nutrients recovered from cover crops, should be given credit in annual fertility plans, as should long term increases in general soil fertility. This will assure that your investment in cover crops pays off economically in the long run.

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How are cover crops affecting my nutrient levels?

This is an increasingly relevant question as cover cropping regains popular favor, because cover crops - *especially after multiple years of cover cropping* - can begin to drastically change how nutrients are cycled in your soils. Consider that ≤ 50% of fertilizer N given to a cash crop may actually be recovered by it. If the crop needs more N (and it very often does) it will need to come from the soil, and the % fertilizer N that your crop *didn't* recover is free to be lost to the environment, *and from your bank account*. If you've ever wondered, or weren't considering how significant your cover crops might alter your nutrient budgets, there are a number of ways you can begin to account for the effects of cover cropping.

Fig. 1) Soil pit excavation illustrating forage 'daikon' radish (*Raphanus sativus var. longipinnatus*) cover crop taproots reaching into deep layers of the soil profile. *Photo courtesy Natalie Lounsbury, University of Maryland.*

Cereal rye is the primary go-to cover crop for many growers in the northeast and beyond. Cover crop opportunities and popular understanding of cover crops and their benefits are expanding in leaps and bounds though. The recent popularity of mixed-species cover crops, aka, "cover crop cocktails" has added an unprecedented level of complexity to reliably understanding effects from cover crops. But, the theory behind these mixed-species cocktails highlights principles that help us understand how an individual species might affect nutrient budgets on our farms.

Cover crops have a number of traits that allow them to perform a variety of "services" for your farm's soils. Deciphering what these services are for an individual species is a key part of beginning to understand how cover crops affect nutrient budgets. Nutrients in natural systems by-in-large cycle nutrients tightly in a self-regulating way without inputs. And without soil disturbance, deep-rooted perennial species (Figures 2 and 3) and a highly developed ecosystem of decomposers dominate these systems. In annual crop systems that are absent of perennials, often disturbed (tilled), and demand fertility inputs (*particularly N*), we can attempt to improve the efficiency of nutrient cycling on our farms with cover crops. Generally, all cover crops "scavenge" nutrients that leftover from cash crops, but some are more effective than others (not all perform well on residual nutrients alone), and legumes can actually *add* N to soils that wasn't there before. For simplicity's sake, these services can be organized into a few simple categories by the plant family of the more commonly used cover crops.

Grasses: Cheap, reliable, and often cold-hardy, grasses (especially small grains) are the most widely used family of cover crops. Their fibrous root systems (Fig. 3) are excellent for stabilizing soils,

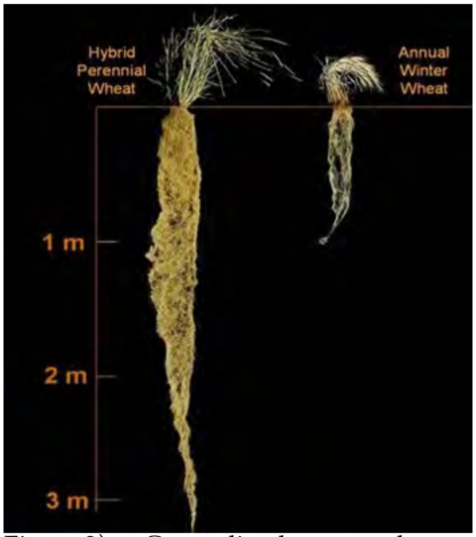

Fig. 2) Generalized annual vs. perennial grass root systems. *Image courtesy The Land Institute, Salina, KS.*

improving soil structure, building soil organic matter, and their ability to quickly form a thick canopy of competitive cover gives good weed suppression potential to boot. Grasses are also good nutrient scavengers, their fibrous root systems tend to reach wide and ubiquitously, especially in the upper layers of the soil; roots commonly will reach a maximum depth at 3-4 ft. Winter cereals scavenge more nutrients than fall-planted spring grains since they overwinter and will be taking up nutrients anytime when temperatures allow for plant growth. An over-wintered rye cover crop, for example, may commonly scavenge 25-50 lbs./ac by the time it is terminated. Winterkilled spring grains (like oats) may generally scavenge 10-20 lbs./acre *less* than overwintering grains. Summer-planted warm season grasses like millets, teff, sorghum-sudangrass etc. may capture more N than small grain cover crops *if it's there to scavenge*, but may excel more at soil organic-matter building services; certain sorghum-sudangrass cover crops been recognized for soil nematode suppressing properties as well.

Brassicas: Cool-season brassicas appear to be being adopted at the most rapid rate by growers, thanks to the popularity of forage or 'daikon' radish (*Raphanus sativus var. longipinnatus*) and it's ability to penetrate compacted layers in soils with an aggressive taproot (figure 1). Brassicas are also recognized for weed and disease control services due to their ability to produce sulfur-rich compounds called glucosinolates in their tissues. These compounds are capable of inhibiting weed seed germination and diminishing soil pathogen loads. Brassica species in general impart this service, but certain species excel in these services more than others; several species that were selected specifically for this purpose in Italy are now commercially available in the US, and are marketed as "biofumigation" crops. Biofumigants are being currently tested most widely for suppressing soil-borne disease in potato, cucurbit, and nightshade crops and for nematode suppression. Brassicas are also often very weed-competitive in general due to an ability to respond to available fertility and quickly form a weed-suppressive crop canopy.

In terms of nutrient budgets, brassicas generally root relatively deeply at a rapid rate; this ability makes them good candidates for bringing nitrates and other soluble nutrients (along with water) that have moved to deeper layers in the soil back to the upper soil layers. Species like forage radish (which is a biennial with a large tuberous taproot) are standouts among brassicas for this service though (Fig. 1). Brassicas also don't depend on mycorrhizal soil fungi (unlike grasses, legumes, and most other plant families) to aid them in nutrient acquisition, and theoretically, brassicas should be well adapted to scavenge nutrients in soils that have long histories of tillage with annually disturbed fungal growth networks. Brassica species are highly responsive to nutrient levels and may commonly scavenge 100-200 lbs. per acre if the residual N is there to scavenge; counter-intuitively, brassicas may need at least ~10-15 lbs. of starter N fertility if N is low in the surface soil layer in order to begin reaching N stores in deeper layers. It is also worth noting too that many winterkilled brassicas may lose some of the N they recover over winter and into spring, depending on environmental conditions.

Legumes: Nitrogen is the only nutrient that can be considered "renewable", and legumes are the single most powerful way to biologically renew N stores on your farm with a cover crop. Legumes demand a lot of N to meet their biological needs. So, when soil N isn't coming in fast enough, legumes invest in a relationship with certain soil bacteria (rhizobia) capable of turning airborne N gas into plant available N ("N-fixation") in exchange for some of the carbon they produce from photosynthesis. Other cover crops may *scavenge* and *recycle* nutrients better, but no other cover crop can actually *add* more N to soils than was there previously. Nitrogen fixation by legumes is variable by species and plant growth; for instance, beans are notoriously poor N-fixers that may produce 0-30 lbs. of N per acre, while a crop of hairy vetch or red clover may fix anywhere between 100-200 lbs. of N per acre. Some legumes fix N better than others when residual soil N levels are already high. Crop stage also plays a role; legume N-fixation generally is at its maximum around the they are in full bloom, so killing legumes before this stage is cutting the plant short of its ability to add N to your soil. After legumes begin to invest in seed production, legumes generally move their resources away from N-fixation. Legumes should also be inoculated with the correct type of rhizobia. This is a very affordable way to ensure that your legumes 1) have N-fixing rhizobia to associate with, and 2) associate with a strain of rhizobia that ensures that N-fixation potential is high. Low availability of other nutrients in your soils will also negatively affect N fixation, as will soil saturation and drought. Perennial legumes like red clover may have the added benefit of deep taproot development to scavenge nutrients and water from soil deeper layers (Fig 3); if left to grow long enough (>1 year), these perennials can also contribute a greater amount of carbon to soils.

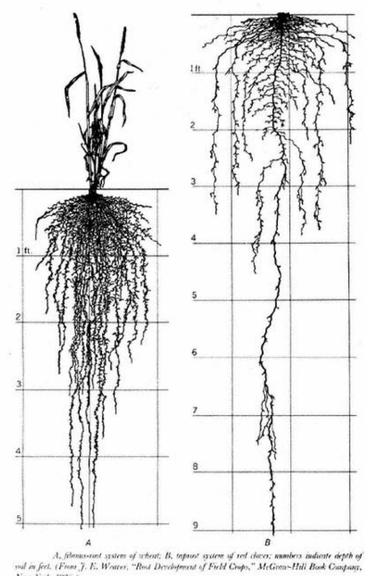

Fig. 3) Fibrous wheat root system (annual), left, vs. red clover taproot (perennial), right. *Image from "Root Development of Field Crops" By John E. Weaver, 1926.*

Others: Sunflowers and buckwheat (the former as a component of cover crop mixtures) are probably the most common cover crops that otherwise fall outside of the three aforementioned plant families. Sunflowers (especially giant varieties) produce a prodigious amount of biomass that can be returned to soils as an organic matter builder, and have strong taproot systems that can reach deeply into soils to recover nutrients. Sunflowers have *not* been extensively studied as cover crops though to date, but estimates of biomass from other sunflower studies suggest that 5000-8000 lbs./ac of dry matter containing 90-150 lbs. of N may be reasonable metrics to keep in mind. Buckwheat thrives in the warm temperatures of midsummer where it grows at a blinding rate and is infamous for suppressing weeds, attracting pollinators, conditioning soils with its fine lateral roots, thriving on nutrient-poor soils, and increasing phosphorus availability to subsequent crops. Buckwheat may commonly capture ~50 lbs./ac of N as a cover crop; its ability to extract P from soils may not always be consistent or significant though, especially from soils most typical to humid regions (acidic, non-calcareous).

Payback time: With these services in mind, it's now important to think about think about how nutrients contained in cover crop residues are then released back into the system. Nutrient release from plant residues is "ecologically mediated"; temperature, air and water availability (think soil structure and texture), soil pH, the soil decomposer community, and residue quality all interplay to affect crop residue decomposition and nutrient release. Soil microbes are ultimately responsible for the final molecular conversion of organic matter-bound nutrients back to common plant-available forms though. Microbial activity drops considerably in temperatures below ~40° F, and raises significantly above this generalized threshold. As a general rule, envision that decomposers and soil microbes will be very busy breaking down organic matter and mineralizing nutrients in a warm, well-aerated, moist environment (Fig. 4).

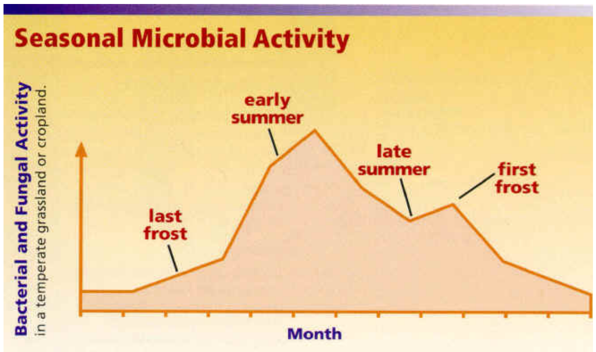

Fig. 4) Generalized soil microbial activity throughout the year by temperature. *Figure courtesy Elaine R. Ingham, Oregon State University.*

Tillage can temporarily incite these conditions in surface soils and help with residue management, but can simultaneously disrupt many beneficial longer-term soil nutrient cycling/fertility processes. Tillage can lead to a *net loss* organic matter over time by breaking it down more quickly than it's replenished, destroys soil structures that aid in soil aeration and soil moisture management, and compromise soil food webs that can be beneficial to plant growth and health. The bottom line with tillage is that there is a tradeoff with how it can be used to manage cover crops. Reduced tillage approaches are generally being accepted as the direction to achieving longer-term soil health even if it means that the short-term benefits of tillage are forfeited.

Crop residue quality is the other major factor to consider from a management perspective. Residue quality is affected by species and how mature a crop is when it's terminated. Crop carbon-to-nitrogen (C:N) ratio is the simplest way to assess residue quality (Fig. 5), although you may also want to consider lignin content (the "woodiness" of a crop) as well. Crop residues have fractions that range from readily decomposable ("labile") to those resistant to decomposition ("recalcitrant"). The C:N ratio and lignin content of a crop increases as the crop approaches maturity (Fig. 6), and consequently so does the proportion of plant residues characteristic of the more recalcitrant end of the residue quality spectrum. Therefore, residue quality largely determines how much organic matter from a crop's residues are 1) *labile* and likely to quickly break back down into plant available nutrients, and 2) how much will be more *recalcitrant*, releasing nutrients slowly and/or contributing to soil humus. Each fraction is important, and cover crops can be managed to contribute more to one or the other pool. Younger plants are generally *all* quite labile, and legumes are generally more labile than most non-legume cover crops, even when mature (Fig. 6). Brassicas can also be very labile if they have taken up an abundance of N, as can buckwheat. Grasses tend to be labile for a shorter period of time; rye infamously will begin to cause a nutrient "tie-up" (a net "immobilization") after it begins to grow taller than ~6". This is the case for any cover crop where the C:N ratio begins to climb past 20:1 to 40:1, (Fig. 5) and when lignin content climbs. Microbes need to maintain a certain ratio of C:N in their bodies (~8:1), and when C sources are high, they will use available N to maintain the correct ration of C to N intake and temporarily compete with plants for available nutrients. This net immobilization of nutrients will occur until microbes have consumed the readily available carbon and, in turn, begin to die-off and re-release nutrients contained in their bodies. The opposite can occur when residues are labile

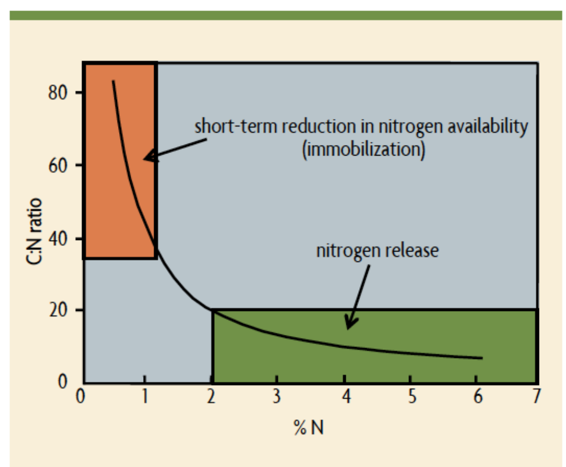

Fig 5. Generalized N release/residue quality relationship. *Image from "Building Crops for Better Soils: Sustainable Crop Management" by Magdoff & van Es, 2009, based on data from Vigil and Kissel, 1991.*

and nutrients within the crop residues are more than sufficient; microbes will then excrete/release excess nutrients in plant available forms (a net "mineralization"). Note that in mixed species stands, this phenomenon can be used to your advantage with regard to managing residue quality, but requires a good understanding in order to utilize mixing species for the desired outcome. For instance, mixing a cereal into a legume stand will likely *increase* the overall C:N ratio of the stand and cause nutrients to be released more slowly (which may desirably prevent losses of excess legume N that may mineralize faster than a crop can take it up), or vice versa if a legume is added to a cereal stand.

Other factors to consider: Nitrogen fertilizers can factor in as well, but the interactions are complex. In short, N fertilizer can sometimes speed up decomposition in fresh, labile residues, but conversely tends to inhibit decomposition of more recalcitrant residue fractions and soil organic matter. This is a consideration with regard to building soil organic matter, because abundant fertility can also increase residues returned to soils from crops- sometimes critically so. A nutrient-starved crop is a dysfunctional crop, whether it's for market or for soil improvement. This is another case for assuring that your fertility is adequate for functional crops, while still being careful to avoid over-fertilizing.

Biodiversity with cover crops is another factor to consider. Similar to what can occur with plant disease buildup in monocultures, studies in ecology have illustrated that over time, plants can inadvertently select for microbial communities that specialize in breaking down their own residues. This might be positive or negative, depending on your goals. If the same cover crops are always used (or if cash crop and cover crop residues are similar) you may 1) build up a microbial community that breaks those residues down efficiently for fast nutrient release and residue management (with the risk of pathogen build-up aside), but 2) in turn may also negatively affect your capacity to build soil organic matter and soil nutrient retention.

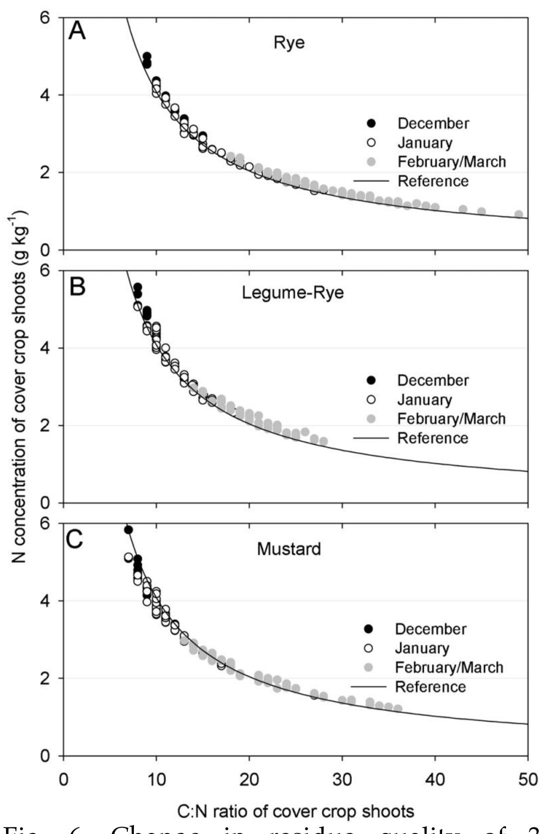

Fig. 6. Change in residue quality of 3 different cover crops over 3 months of growth in California. *Figure from "Winter Cover Crop Seeding Rate and Variety Effects during Eight Years of Organic Vegetables: III. Cover Crop Residue Quality and Nitrogen Mineralization", by Brennan et al. 2012.*

Give credit where credit is due: Avoid the pitfall of not giving a good cover crop stand credit in your nutrient budgets. This becomes more true the longer you have been cover cropping (recall that each % of soil organic matter = ~20 lbs.+ of N per acre/year) and/or if you have had successful legume cover crops 70-200 lbs./ac Studies have shown that successful cash crops may be grown entirely on legume N, and it's likewise not uncommon for growers with advanced cover cropping experience to cut back significantly on fertilizer inputs. This will understandably make some growers nervous because more risk is assumed, but if you aren't giving your cover crops a credit currently because of risk, trial some small areas to monitor how your crops respond with regard to the cover crop that preceded it (species, biomass produced, estimated nutrient return, residue quality at termination). Observation, experience, and knowledge are key to reaping the benefits of cover crops for building soil health, for keeping nutrients on the farm, and for keeping money otherwise spent on excess fertility in your bank account.

For more information:

- Cornell cover crops: http://covercrops.cals.cornell.edu
- Penn State cover crops: http://extension.psu.edu/agronomy-guide/cm/sec10/sec103
- *Managing Cover Crops Profitably* free PDF: http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition
- NRCS comprehensive guide to northeastern cover crops: http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/nypmcpu10645.pdf
- NRCS C:N ratio article: http://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcs142p2_052823&ext=pdf
- Oregon State U article on estimating N credits from cover crops: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/34720/pnw636.pdf
- *Making the Most of Cover Crop Mixtures* article: http://www.hort.cornell.edu/expo/proceedings/2013/Cover%20Crops/Cover%20Crops%20White%20Mixtures.pdf. There will be an upcoming revised and enhanced version of this article soon on eXtension.org.
- Penn State cover crop mixtures webinar: http://www.extension.org/pages/71186/using-cover-crop-mixtures-to-achieve-multiple-goals-on-the-farm-webinar#.VI8MaPjF8lA
- Penn State cover crop webinars: http://extension.psu.edu/plants/sustainable/courses/cover-crop-innovations-webinar-series/webinars

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