DIVERSE COVER CROP MIXES FOR GOOD SOIL HEALTH

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The importance of New York agriculture going into the next century is predicted to increase due to the abundance of water, a trend toward moderating temperatures and increasing cost of fossil fuel making local food production more competitive. The long term sustainability and preservation of farm land will become more important. The use of cover crops for improved soil health and nutrient cycling will play an important role in this sustainability.

The interest in the use of diverse cover crop mixtures is being fostered by small groups of farmers and conservation agency personnel who have been early promoters and adopters of no-till and cover cropping. They have seen the synergistic benefit of the combination of these two conservation practices. These early adopters are now evaluating the use of diverse cover crop mixes with combinations of up to 15 species. In Burleigh County North Dakota, on farm diverse multi-species cover crop trials were initiated in 2006 and have been expanding yearly to other farms in the area as well as in other states. Case studies were developed in cooperation with NRCS showing very promising results which can be found on the Burleigh County Soil Conservation District website (http://www.bcscd.com/). At this time there is no peer reviewed published research to report on in the Northeast and little elsewhere in the country on the use of cover crop mixes other than binary mixes and some preliminary work on four species mixes in North Carolina (Creamer and Baldwin 1997).

Cover crops offer many benefits for agriculture productivity and sustainability while reducing off farm environmental effects. For agricultural productivity, sustainability and soil health these include: erosion control, compaction remediation, increased water infiltration and storage, improved soil biodiversity, increased organic matter, nitrogen fixation, and improved nutrient recycling and retention of macro and micro nutrients. Environmental benefits include: reduced nutrient leaching, reduced sediment and phosphorus deposition, reduced runoff, and increased carbon sequestration; while suppression of weeds, diseases and nematodes and improved beneficial insect habitat results in reduced pesticide use. Other conservation benefits include: pollinator enhancement, wildlife enhancement as well as aesthetic value (Stivers-Young and Tucker 1999; and Snapp et al. 2005).

There are several reasons why producers do not choose to use cover crops. Vigorous living cover crops in the spring can remove water needed for subsequent crops and may provide alternate host or refuges for insect pests and disease. A large amount of dead cover crop residue in the spring delays soil warming and creates difficulties in incorporation and subsequent seed bed preparation. If cover crops are not managed appropriately late harvested grass cover crops or mixtures with high C: N ratios, if incorporated, can tie up nitrogen depressing the yield of subsequent crops. Hard seed of vetch or seed of annual ryegrass, mustards and millets may create future weed problems. Although increased soil microbial activity may reduce the incidence of some soil borne diseases, the decay of some cover crops can lead to higher levels of diseases such as *Pythium* spp. and promote slugs and insects. Opportunity costs due to foregone income from cash crops can be an important disincentive to the adoption of cover crops that compete in time or space with cash crops (Stivers-Young and Tucker 1999; and Snapp et al. 2005).

Soil health and quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil quality integrates the physical, biological, and chemical components and processes of a soil. For a specific kind of soil, a healthy soil has relatively high: total and particulate organic matter, nitrogen mineralization potential, microbial biomass and respiration, total aggregation and aggregate stability, cation exchange capacity, porosity, infiltration rate, available water capacity and low; bulk density, compaction and surface crusting. There are other soil quality parameters that can be evaluated at the Cornell Soil Health Lab (Gugino 2009). Well managed cover crops can increase soil organic matter having a positive effect on a soil's physical, biological and chemical properties.

The use of no-tillage systems greatly increases the benefits of cover crops and vice versa. No-till systems increases water conservation by maintaining cover crop residues on the surface. No-till systems reduce the disruption of the soil reducing: soil erosion, water runoff, organic matter oxidation and increases; infiltration and all of the benefits of improved organic matter accumulation. Stratification of the soil profile as result of no-till is important for macro invertebrates and soil micro-organisms. Tillage leads to unfavorable effects such as: soil erosion, soil compaction, loss of organic matter, degradation of soil aggregates, death or disruption of soil microbes and other organisms including; mycorrhizae, arthropods, and earthworms. Continuous no-till needs to be managed very differently in order to maintain or increase crop yields. Residue, weeds, equipment, crop rotations, water, disease, pests, and fertilizer management are just some of the many details of farming that change when switching to no-till. Tillage generally increases the amount and speed of nitrogen mineralization of soil organic matter which may increase or decrease synchrony of nitrogen release depending on the timing of the subsequent crop's nitrogen needs.

There are opportunities for the use of cover crop mixtures in vegetable crop production and following small grain cereal crops. Some summer vegetables are planted later in the spring and are often harvested earlier in the summer or fall than many common agronomic crops such as field corn. This allows for a more diverse selection or combination of cover crops to choose from. This timeframe allows for the use of many legume species due to the earlier cover crop planting dates in the late summer as well as the additional time for nitrogen fixation by leguminous cover crops the following spring. Some sweet corn is planted later and harvested earlier than field corn. Vegetable crops are often irrigated reducing the impact of late terminated cover crops on soil water supplies. Irrigation should also increase soil nitrogen availability by enhancing nitrogen mineralization of cover crop residue. Do not use cover crop species related to vegetable crops that will be grown near or as a subsequent crop to avoid spreading insect pests and diseases.

The selection of species and management of cover crops for their carbon to nitrogen ratio (C:N) is important when developing cover crop mixtures. One of the most important drivers in crop production is nitrogen; while for long term soil quality, health, and sustainability the driver is carbon. The ratio of C:N in the cover crop or mixture effects how much and when the nitrogen contained in the cover crop will be available for subsequent crop uptake. When C:N ratios are less than 20-25 nitrogen is released. When cover crop C:N ratios exceed 30 the soil microorganisms that breakdown cover crops will have to take up nitrogen from other sources as the cover crop does not have enough nitrogen to break down its biomass, this is referred to as immobilization. This results in the need to add additional nitrogen for the subsequent crop. Often cover crop management for nitrogen and organic matter are at the expense of the other. To obtain more biomass the cover crops are grown longer, closer to maturity and the C:N ratio will go up reducing the availability of the nitrogen to the subsequent crop conversely the strategy may be to terminate the cover crop early thereby increasing nitrogen availability but reducing overall biomass and organic matter production. For organic nitrogen to be used by subsequent crops, it must undergo mineralization. The timing of availability of this released nitrogen to the need of the subsequent crop is termed synchrony. This will be affected by the C:N ratio, soil temperature, precipitation, soil type, tillage practices, time of termination of the cover crop (spring or fall or time in spring) and interval between the planting of subsequent crops and the timing of the subsequent crops nitrogen demand. If the nitrogen is mineralized too quickly due to a very low C:N ratio, less than 20, and available nitrogen exceeds the crop need at that time, this nitrogen can be subject to leaching losses. When C:N ratios are high the nitrogen can be tied up by soil microorganisms reducing the availability of the nitrogen for the crop when it is needed, requiring at a minimum starter fertilizer, with a follow up pre-sidedress nitrate test (PSNT) to determine if additional fertilizer is needed. When higher, soil organic matter and soil organic nitrogen levels are achieved and maintained annual fertilizer nitrogen inputs may be reduced. High soil organic matter and nitrogen reserves can buffer crop yields; if high rainfall early in the season leaches out early applications of fertilizer, organic nitrogen may be mineralized later in the season for subsequent crop use and partial yield stabilization. Increase in organic matter improves water holding capacity, aeration and nutrient supply capacity by increasing cation exchange capacity (CEC).

There have been a few studies which compared cereal rye, hairy vetch and the combination of hairy vetch plus rye cover crops for their C:N ratio and the subsequent crops response to additional Nitrogen fertilizer. One study conducted in Maine compared alfalfa, rye, and rye plus vetch cover crops with sweet corn. The rye and hairy vetch were planted mid to late August, the alfalfa was planted in early May and the corn was planted the first week of June the following year. They found that sweet corn following alfalfa or vetch plus rye generally did not respond to additional nitrogen fertilizer as it did following rye grown alone. They concluded that the alfalfa and vetch plus rye cover crops supplied all or nearly all of the nitrogen required by the sweet corn with a fertilizer replacement value of 50 - 135 lb/N/ac (Griffin 2000). Other studies reviewed showed that there was immobilization of the nitrogen from the cereal rye component in the mixes. In a study in Kentucky with sweet corn, although the nitrogen contents of the vetch and biculture (vetch plus rye) cover crops were similar in the 0 nitrogen treatment, sweet corn yields in two out of three years were significantly greater following vetch than following the biculture cover crop (Cline and Silvernail 2002). Similar results have been obtained in studies with no-tilled field corn in Maryland (cover crops were conventionally established with moldboard plowing). Compared to vetch N, biculture (vetch plus rye) N apparently is not fully available to following crops due to microbial immobilization of the nitrogen accompanying the decomposition of the rye component of the biculture cover crop (Clark et al. 1997). The rye monocultures resulted in the lowest yields of the subsequent crops and required the most supplemental nitrogen to maintain adequate yields. These studies indicate that with multiple cover crop mixes, especially when starting out, the management of the carbon to nitrogen ratio will be paramount for nitrogen availability and synchrony and that the use of fertilizer or nitrogen rich manures or compost will be needed to offset nitrogen immobilization when C:N ratios are high.

One of the rationalizations for the use of complex diverse cover crop mixes is to maintain or increase soil microbial diversity which is an indicator of good soil health. In the literature there is some evidence and debate between above ground diversity and their associated roots and soil micro and macro fauna diversity. There is also debate as to what that means in relation to their function within the soil ecosystem. One article reviewed reported that differences in species root exudates can affect diversity and quantity of soil micro-organisms in the rhizoshere (Kowalchuk 2002). Another reported that vegetation influences soil invertebrate and microorganism communities through the abundance, quality and distribution of their organic resources (residue and root exudates) produced in both time and space (Giller et al. 1997). There is still much research needed in this area. A square meter of an organic temperate agricultural soil within the plow layer may contain 1000 species of organisms with population densities in the order of $10^6/m^2$ for nematodes, $10^5/m^2$ for micro arthropods and $10^4/m^2$ for other invertebrate groups. One gram of soil may contain over 1000 fungal hyphae and up to a million or more individual bacterial colonies (Altieri 1999). Cover crop mixtures can provide a wide variety of plant types resulting in diverse easily decomposable residues with diverse root systems to support the soil biota. It is important to maintain a system with residue cover and living roots throughout the year. With individual cover crop species known for having mutualistic relationships with soil microorganisms it is reasonable to expect potential benefits to soil biotic diversity and soil health with the use of cover crop mixtures.

The use of diverse cover crop mixes can be used to enhance pollinator habitat or refuges for beneficial insects. Insect pests usually exhibit higher abundance in monocultures than in polycultures. This is partly due to more stable populations of beneficial insects (predatory and parasitic) in polycultures from continuous availability and diversity of food sources and micro habitats. Studies have indicated the importance of adjoining wild vegetation in providing alternate food and habitat to natural enemies that move into nearby crops. Diverse cover crop mixtures with species which include plants which enhance beneficial insects can be part of an IPM strategy. Extension of the cropping period or planning temporal or spatial cover cropping sequences may allow naturally occurring biological control agents to sustain higher populations levels on alternate hosts or prey and to persist in the agricultural environment throughout the year (Altieri 1999).

Weed control by cover crops is caused by direct competition with weeds, the use of their residue as mulches and in some cases allelopathy; thereby eliminating, or reducing the rate, application number, or types of herbicides needed. Allelopathy, in this context, is the production by plants of biochemicals that have deleterious effects on the growth and survival of other plants. The use of complex cover crop mixes may take advantage of the allelopathic suppression of weeds. Allelopathy has been shown to be species-specific phenomenon therefore a broader spectrum of weed control may be obtained by growing mixtures (Creamer and Bennett, 1997). Allelopathy needs to be taken into consideration and managed when direct seeding subsequent crops. Some cover crops like millets and sudangrass used as smother crops perform better with the addition of nitrogen so the use of mixes including legumes such as sunn hemp or soybeans can increase the efficacy of the smother crop and reduce nitrogen immobilization. Forage radish (*Raphanus sativus*), rape seed (*Brassica napus*) and mustards such as Indian mustard (*Brassica juncea)* suppress the majority of winter annual weeds compared with a bare fallow, primarily through competition in the fall and light interception by the residue in spring as well as some weed seed decay (Stivers-Young, 1998). Follow up weed control is usually necessary when brassicas are used for weed control.

Cover crops can have varying effects on soil pathogens some positive and some negative. Brassica species suppress plant parasitic nematodes and soil borne diseases such as *Pythium* species by producing glucosinolate containing residues. Sudangrass is known for suppression of root-knot nematode (*Meloidogyne hapla*) in lettuce production, this may be caused by the release of cyanogenic compounds during decomposition of the sudangrass residue. Some decaying cover crops which do not contain suppressive compounds have been reported to support *Pythium* species. Legumes cover crops may support populations of lesion nematodes (*Pratylenchus* spp.), this may complicate management of some mixes although the mixes may dilute the effects of monoculture legumes in this instance.

Some of the above benefits discussed for cover crops and cover crop mixtures may need to be in conjunction with no-till and/or may evolve over several years of consistent use to obtain changes in the soil health and nutrient cycling. Increases in organic matter and nitrogen will provide some stability of yields over varying seasons with different precipitation patterns. Changes in soil microbiology responsible for disease suppression may also take time.

The species used for cover cropping have diverse morphological, physiological and compositional make up. Cover crop species differ in their vegetation type; grass, legume or forb; morphology both above ground and below ground (root architecture); and their life cycle annual, perennial or biennial. Cover crops differ in their rate of growth and time to flowering; their response to temperatures (cool season or warm season); and their tolerances to frost, shade and soil conditions especially soil moisture and drainage. They also differ in their chemical composition especially carbon to nitrogen ratios; their nutrient uptake, recycling and nitrogen fixing abilities as well as differences in ease or difficulty in termination. With all of these variables to choose from it is thought that the combination of cover crops can be used to exploit niches and allow for synergistic behavior improving the overall performance of cover crop systems.

Cover crop species are grouped into six major categories: 1) cool season grasses; 2) cool season legumes; 3) cool season broadleaves 4) warm season grasses; 4) warm season legumes; and 6) warm season broadleaves. A mixture should combine species from as many categories as practical based on the planting season. Cover crop species can also be placed into functional groups for example, nitrogen fixing, nitrogen uptake, and compaction remediation. A good reference for organizing species into their functional groups can be found in the book "*Managing Cover Crops Profitably*". Cool season grasses especially cereal grains are noted for high biomass, erosion control, weed suppression (cereal rye noted for allelopathy), high nitrogen uptake and recycling and high C:N ratios. Brassicas are noted for their fast cool season growth, high biomass, high nitrogen uptake and recycling, and their weed, disease and nematode suppression. The large deep tap roots of forage radish (*Raphanus sativus* var. niger L. cv. Daikon) and other brassicas allows for soil compaction remediation, phosphorus uptake and for subsequent crop roots to travel in their channels following decomposition. Brassicas are also known for pollinator enhancement and low C:N ratios. Legumes are noted for nitrogen fixation, with some winter annuals producing high biomass, soil compaction remediation and phosphorus uptake (alfalfa and sweet clover), pollinator enhancement and low C:N ratio. Warm season annual grasses especially sorghum, sudangrass and hybrids are noted for high biomass, allelopathic properties, weed control, soil compaction remediation and high C:N ratios. Buckwheat is noted for weed control, nematode suppression, allelopathy, phosphorus uptake, pollinator enhancement and a low C:N ratio. Other cover crops which are routinely being used in diverse cover crop mixes are sunflowers, millets and teff. Other species are being considered for use in mixtures as they are becoming economical and tested for their use, such as the legume sunn hemp (*Crotalaria juncea*).

The combination of cover crops can sometimes act synergistically or complementary to overcome some of the concerns of cover cropping or enhance overall performance to meet or satisfy multiple objectives. In mixes with cereal grains some species like hairy vetch, Austrian winter pea and crimson clover, may survive winter better than when planted as monocultures. With mixes there is potential for more biomass and macro and micro nutrient recycling by taking advantage of more below ground and above ground niches to utilize nutrients, water and light. The mixing of cover crops with residues of different C:N ratios may be one approach to managing rates of decomposition and nitrogen release that can help to optimize the efficiency with which fixed or recycled nitrogen is used. There has also been findings that the C:N ratio for the rye component in a rye plus hairy vetch mix is lower than when the rye is grown in monoculture. Grasses and brassicas usually germinate and establish effective root systems more rapidly than do legumes. Since non-legumes are generally better at obtaining nitrogen from the soil, the non-legume depletes soil nitrogen leading to increased legume nodulation and biological nitrogen fixation. The non-legumes may uptake some of the nitrogen being fixed resulting in an overall increase in potential nitrogen availability (Snapp et al. 2005).

An example where a mixture may be beneficial is where there is a need for nitrogen uptake to prevent leaching in the spring, erosion control prevention, compaction remediation and a need for additional nitrogen; a combination of cereal rye, hairy vetch and forage radish may be able to, with management meet or satisfy some or all of those objectives. The combining of several species within functional groups to create an even more diverse cover crop mixture should be considered to improve establishment reliability and overall performance; due to differences in their seedling vigor, rooting behavior and environmental tolerances.

When developing mixes there are multiple factors to consider to insure compatibility. Select species which have similar heights to provide a uniform canopy such as sorghum x sudangrass hybrids and sun hemp, or millets and soybeans. Understory species which are shade tolerant like red clover are frequently used frost seeded into cereal grains or interseeded into standing corn and may be used in some mixes. Erect cereals and the viney growth habit of hairy vetch can be complementary they frequently produce larger amounts of biomass when they are planted together than when they are planted as sole cover crops. Root systems should be complementary such as between grasses and legumes, where superficial fine roots of grasses ameliorate shallow compaction and tap-rooted legumes reduce deep compaction. The seedling growth and vigor of some species such as brassicas especially radishes are very high and need to be planted either in separate rows or at rates kept low enough in the mix to allow for the establishment of other species. Mixes need to be complementary in their adapted season of growth and growth rate to fit between rotations. Management of the mixture for flowering times and seed set may be needed for the control of problem species such as millets or mustards to prevent them from going to seed. Synchrony in flowering or maturity is important for mechanical termination or termination for proper C:N ratios. Seasonality of cover crops need to be taken into consideration if relying on frost to kill the cover crop; or conversely the use of a mixture of warm and cool season species planted in the summer then over wintered for rehabilitation of land allowing for increased biomass, better recycling of nutrients and better C:N ratio. There are differences in frost hardiness among brassica species and cultivars, for example forage rape (*Brassica napus*) cv. Dwarf Essex may overwinter compared to the radishes. An overwintering brassica species or cultivar, may be a more appropriate choice of brassica cover crop for nutrient cycling when planting on coarse-textured soils and when the subsequent crop will not be planted until late spring. There is also a need to take into consideration soil drainage characteristics when selecting species in the mixture; for example brassicas can tolerate heavier soils than legumes and may be suited to rehabilitating sites with inadequate drainage, soil compaction and soil borne diseases. Another strategy when seeding into soils with variable drainage, is choosing a mixture of species with differing soil drainage tolerance levels so the different species will fill in and grow in their adapted areas providing for more complete cover and biomass production.

The seed size of the individual components in a seed mixture may vary such as hairy vetch and crimson clover, or sorghum and teff. Their varying seed size can fill different seed bed niches when broadcasting and harrowing, thereby improving overall cover crop establishment. If tilling, cultipacking to improve seed to soil contact is recommended or seeding on freshly tilled soil and having the seed washed in by the next rain. Small seeded species such as teff, some millets, brassicas or legumes require shallow planting depth and a firm smooth seed bed for uniform and successful stands. In most cases seeds should be purchased and combined into groups of similar sizes as opposed to being purchased as a complete mix. When constructing mixes the seeding method and equipment need to be taken into consideration since seeds of differing sizes may settle in seed hoppers effecting the uniform distribution of the seed. One strategy would be to use a seed drill with multiple seed hoppers and to combine seeds of similar sizes into different hoppers. Another strategy could be to use a combination of cover crops from the different function groups that have similar seed size and planting depth and mix them together in one hopper. For example combining millets with brassicas and crimson or red clover for an early summer seed mix, they can all be seeded with a Brillion seeder or a drill, in one hopper then seeded at the same depth. Diverse mixtures with differing seed sizes can also be mixed and added into one seed hopper in small increments during the seeding operation to help maintain seed proportioning, in this case the depth is then set at an intermediate setting of about one inch. It is important to note that seeds of different sizes require different depth of planting, which is difficult to accomplish in one pass. Cover crop seed can be expensive it is important to balance your mixture based on seeds per square foot taking into consideration the cost of the individual components to maintain an economical seed mix. There are cover crop seed calculators available which can help with these calculations.

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