TECHNICAL NOTE

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Cover Crops for Green Manure in the Great Basin

The term "green manure" refers to cover crops that are tilled into the soil. Green manures are mainly grown to increase soil organic matter (OM). This technical note explains how green manures build soil OM, and several other benefits green manures can provide in a crop rotation. It also presents the results for green manure cover crop trials at the Great Basin Plant Materials Center, with two forage soybean *Glycine max* varieties; 'Big Fellow' and 'Large Lad' and a tropical legume, sunn hemp *Crotalaria juncea* 'Tropic Sunn'.

Because of their cold sensitivity, these two legume green manure crops have only about 120 days of growing season available at the lowest elevations in the Great Basin. This prevents the use of these legume green manures for multiple cuttings of hay or in a double-crop system as in regions with a longer growing season. Using the "rule of thumb" value of 3.5 to 4 percent N in legume tissues (Clark, 2007) the above ground biomass produced by these soybean varieties could add from 418 to 453 lb N/acre to the soil. Using a value of 4 percent N for the sunn hemp biomass, the N production was approximately 429 lb N/acre 90 days after planting.

Green manure crops with more cold tolerance, such as winter rye *Secale cereal*, winter wheat *Triticum aestivum*, triticale *Triticum* x *Secale*, canola *Brassica napus*, oil radish *Rhaphanus sativus*, winter pea *Pisum sativum*, hairy vetch (*Vicia villosa*).and oil mustard *Sinapis alba* allow more flexibility in the growing season but would require supplemental nitrogen fertilizer for optimum biomass production. Production in the cooler months in Nevada would also depend upon the availability of irrigation water.

Soil organic matter is defined by the Soil Science Society of America as: "Soil materials that are saturated with water and have 174 g kg^{-1} or more organic carbon if the mineral fraction has 500 g kg^{-1} or more clay, or 116 g kg^{-1} organic carbon if the mineral fraction has no clay, or has proportional intermediate contents, or if never saturated with water, have 203 g kg^{-1} or more organic carbon." (SSSA, 1987).

This describes the organic fraction of the soil exclusive of undecayed plant and animal residues, largely humic and fulvic acids and other large molecules. Other definitions for OM spanning a wider range of concepts have been used, even to the extreme of including all non-mineral components of the soil in the OM. In this holistic definition, all the animals (including worms, insects, and burrowing rodents) and microbes, and all plant life are included (Magdoff and van Es, 2000). This definition of soil OM is also known as "the living, the dead, and the very dead". In this Technical Note OM refers only to what would be called "the very dead" by the holistic definition. The laboratory term for undecayed plant and animal residue in soil is "trash".

OM is the glue that builds soil structure by cementing soil particles together in randomly oriented aggregates. These soil aggregates create pore spaces that reduce the bulk density of the soil and allow roots, air, and water to penetrate the soil more easily. This provides an improved habitat for the rhizosphere organisms that live on and near plant roots: the soil microbes that promote healthy crop root systems.

Plant growth and decay release polysaccharides, resins, gums, waxes, and other molecules into the soil. If these are resistant to microbial or chemical decomposition they may become OM. When the cover crop residue is consumed and the microbes die and decompose, the remaining substances become OM. As the end products of microbial decay followed by chemical decomposition, the OM carbon compounds are relatively stable. Some of the carbon from carbon dioxide that was removed from the atmosphere by photosynthesis during growth of the green manure cover crop is effectively permanently stored, or "sequestered" as OM in the soil. Some OM is lost when tillage exposes it to sunlight and air, so the increased soil OM provided by a green manure cover crop is most effectively managed in minimum tillage or no-till farming systems.

Soil aggregates generally remain stable until they are crushed by hooves, wheels, or tillage implements. Repeated alternately compacting and re-pulverizing a soil with tillage rapidly diminishes pore space, and increases bulk density. Soils in this condition are less productive and more vulnerable to erosion (Brady, 1997). Some solutions are long-term perennial crops such as sod-forming prairie grass or forest, transitioning the farming operation to no-till, or controlled traffic farming systems. In conventional farming systems compaction is reduced by avoiding traffic and tillage on the soil when it is wet and either adding organic residue such as mulch or manure, or growing a green manure cover crop.

There are several benefits of including a green manure cover crop in the rotation, in addition to OM production. Weed control can be improved when the green manure cover crop is planted in a different time of the growing season than is typical for the usual crops in the rotation. For example, a later planting date provides the opportunity to control flushes of early weed seedlings with cultivation or herbicide. Then the green manure cover crop can be planted into a stale seedbed and become established with less competition from weed seedlings. Different herbicides may be registered for use in the green manure crop, and can control problem weeds that have built up because they were not controlled by the herbicides used in the usual rotation.

The soil OM added by a green manure cover crop improves irrigation efficiency by increasing the water infiltration rate and water holding capacity of the soil. Stable soil aggregates formed by OM reduce the potential for soil erosion by wind or water.

Green manure cover crops can break the life cycle of pests and pathogens by depriving them of their required crop or weed host plants. Certain varieties of oilseed radish, sunn hemp, and white mustard have been developed for use as green manure crops. In addition to the OM these plants provide when they are incorporated into the soil, they release natural soil fumigant thiocyanates and other chemicals that control certain nematodes and other soil pathogens. Increased biological activity during decay of green manure biomass can make the soil less conducive to crop pathogens by increasing the population of beneficial soil organisms.

Legumes are preferred for green manure cover crops because they fix nitrogen from the atmosphere. The nitrogen fixed by symbiotic bacteria living in nodules on legume roots benefits the grower in three ways:

1. The growth of the green manure crop is enhanced by a constant supply of nitrogen at no additional cost to the grower.
2. The grower does not need to apply any extra nitrogen fertilizer to the field to help break down the crop residue, as for straw residue following a grain crop, or non-legume green manures.
3. Some of the nitrogen will become available to the subsequent crop, reducing the need for nitrogen fertilizer.

The timing of availability of the nitrogen to the following crop depends on the rate of breakdown of the green manure by soil microbes (Clark, 2007). Rapid breakdown of the readily-decayed, soft, thin leaf material and the fine roots and nodules can provide available nitrogen for a few weeks to months following incorporation of the green manure biomass into the soil. Thicker, more lignified and more decay-resistant stems and roots release nitrogen over a longer time period. The rate and timing of these potentially overlapping periods of nitrogen availability depend on the carbon to nitrogen ratio, the duration of sufficient temperature and moisture to promote decay, and to a lesser extent, the pH of the soil and the availability of nutrients the decay organisms may need such as phosphorus, potassium, sulfur, and micronutrients.

When active decay of the cover crop residue is in progress, much of the nutrient nitrogen is tied up in the bodies of decay bacteria and fungi, and a host of soil invertebrates that feed on both the green manure residue and the decay organisms. When the food supply provided by the green manure is exhausted, the soil microbes die and release their nitrogen into the soil, providing a pulse of nitrogen that becomes available to crop plants.

During the time when pieces of the green manure plants remain visible as trash in and on the soil, they provide some benefits. The physical presence of crop residues improves soil aeration and water infiltration and stabilizes the soil surface against erosion by wind and water, but visible crop residues are not yet OM.

Some plants grown for green manure cover crops also have the potential to be fed to animals as silage or hay. When the above-ground biomass is removed, that proportion of the potential OM, and nitrogen fixed by legumes, is lost to the soil. However, the root system of the cover crop will provide some OM when it decays, and the other management benefits of including a green manure cover crop in the rotation still remain. If the crop is fed as standing forage, or cut and fed on the field as soilage, the animals will return some of the above ground biomass to the soil as manure, which can break down to contribute OM.

Green manure cover crops can also provide food and habitat for wildlife. Deer in some regions have become particularly fond of forage soybean and mustards such as turnip *Brassica rapa*. Game birds can benefit from the dense cover provided by standing green manure cover crops. Other cover crop plants, such as clovers *Trifolium* spp., sainfoin *Onobrychis viciifolia*, alfalfa *Medicago sativa* and *M. falcata*, and sweet clover *Melilotus spp.*, that are left to flower through the growing season can provide a nectar source and habitat for pollinator insects, particularly native bees, and other beneficial insects.

Some non-legume crop plants that can be used for green manure cover crops include spring or winter canola *Brassica napus*, rye *Secale cereal*, spring or winter wheat *Triticum aestivum*, triticale *Triticum* x *Secale*, and corn *Zea mays*.

Forage soybean trial

Seed of two forage soybean cultivars 'Big Fellow' and 'Large Lad' was purchased from a commercial source. Both cultivars were maturity group VII, and both were glyphosate resistant. Seed was inoculated with rhizobium supplied by the vendor and planted on 28 and 29 May 2009 using a no-till drill. The seed was planted at a rate of 40 lb PLS/acre, 1.5 inch depth in rows 7.5 inch apart in Sagouspe loamy sand, and was flood irrigated the next day. Cool weather with 0.31 inch of rain followed planting. Emergence was seen on 4 June in fields that had been treated with glyphosate in December to control winter annual weeds. Emergence was slower and less uniform in the fields where weeds were sprayed in spring before planting, but they soon also had solid stands of seedlings. The first trifoliate leaf began to unfurl on 8 June.

Growth was slow through June and July, with row closure and complete canopy cover by the second week of July, at which time nodules were visible on the soybean roots. Irrigation water was applied on 29 May, 19 June, 26 June, 9 July, 3 August, 20 August, and 17 September. No pest or disease problems were seen in the soybean fields.

Glyphosate was applied on 4 June at a rate of 20 oz/acre, and on 24 June, 23 July, and 7 August at 32 oz/acre. Glyphosate is a non-selective herbicide with no soil activity sold under various brand names. A foliar application of chelated manganese at 0.05 lb/A was included in the June 24 herbicide application. A few scattered individuals of glyphosate resistant corn that was in the seed were rogued with a shovel. Some flowering was seen in a few areas of the fields in mid-September, but no filled pods were seen. A 26°F frost killed the plants on the night of 30 September.

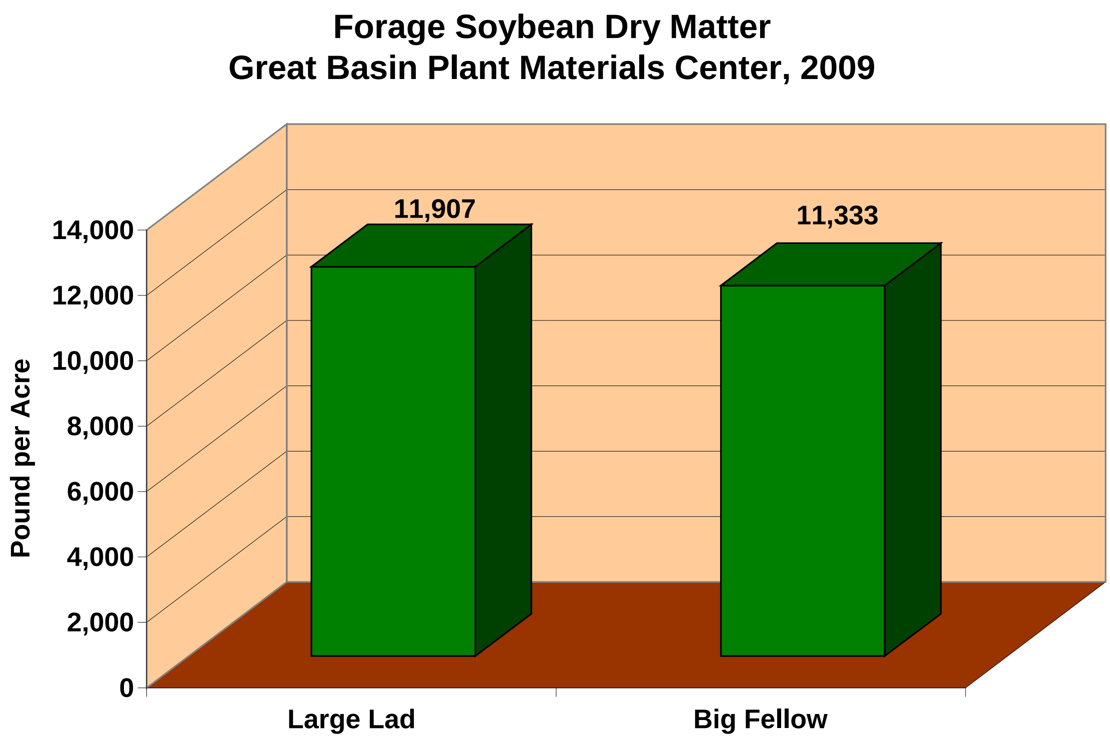
Forage soybean in June, three weeks after emergence. Note the dead and dying weeds in the field as a result of glyphosate application.

Forage soybean in late July. Plants have fully nodulated and have formed a dense canopy, shading the soil and inhibiting weed growth.

Forage soybean in August.

GBPMC Biological Science Technician Mat Humphrey cutting a sample of forage soybean in September, when plants were over 4 feet tall.

Biomass production was measured on 14 September by clipping 3 areas of 5.38 ft^2 in each of the soybean cultivars. Plants of 'Big Fellow' averaged 49 inch tall and 'Large Lad' averaged 53 inch tall. Fresh weight was recorded and samples were placed in a barn and air-dried until no further weight loss was observed after 14 days, and air-dry weight was recorded.



Average air-dry biomass yield of two forage soybean cultivars harvested September 14.

Sunn hemp green manure trial

Sunn hemp *Crotalaria juncea* cultivar Tropic Sunn is a tropical to sub-tropical legume that may flower but is not known to produce seed when grown in the continental United States north of the 28th parallel. On 30 June 2009, inoculated seed of Tropic Sun, a cultivar developed jointly by the University of Hawaii and USDA-NRCS Hawaii PMC, was planted in Sagouspe loamy sand at the Great Basin PMC. This planting was the Nevada location of a nationwide PMC Intercenter Strain Trial to test the range of adaptation of Tropic Sun as a green manure crop.

The previous crop grown in the field was alfalfa, which had been rototilled in 2007, and repeated glyphosate applications and tillage in 2008 were used to create a stale seedbed. Remaining weeds, mainly mallow *Malva neglecta* and yellow nutsedge *Cyperus esculentus*, were treated with glyphosate two weeks before planting. Seed was planted 0.75 inch deep at a rate of 50 lb PLS/acre using a no-till drill with double disc furrow openers spaced 7.5 inches apart.

Full emergence of cotyledon stage plants was observed on 5 July. Nodulation was observed on roots in mid-July. The study was flood irrigated on 30 June immediately after planting, and again on 2 July, 16 July, 3 August, 20 August, 8 September, and 17 September.

Sunn hemp seedlings in June, rows are 7.5 inches apart.

Sunn hemp shown in July with a standard size shovel for comparison.

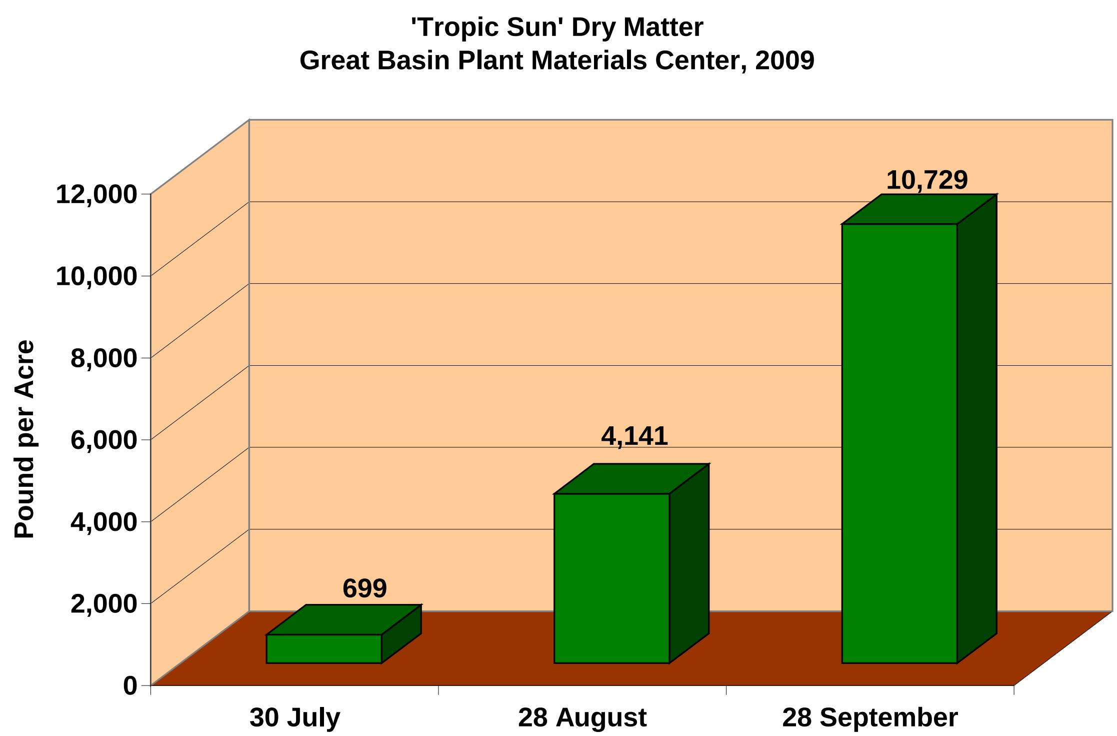
Sunn hemp in August was 5 to 6 ft tall. GBPMC Biological Science Technician Mat Humphrey in the background.

The PMC Manager, Dr. Eric Eldredge, examining the flowers on sunn hemp in September at the Great Basin Plant Materials Center in Fallon, Nevada. Most of the plants are well over 6 ft tall.

Biomass was sampled every 30 days because there is some interest in warmer production areas of the U.S. in growing sunn hemp for a short duration in the growing season to provide nitrogen for a crop planted after the sunn hemp is incorporated into the soil.

The first biomass sample was cut on July 30, from 5.38 ft^2 areas with four replicates of three subsamples, when the average height of plants was 13.5 inches. Samples were air dried in a barn when daytime highs averaged 90˚F for 7 days, until weight loss stopped, and air dry weights were recorded.

The second biomass sample was cut on August 28, when the average plant height was 51 inches. The first flower was observed on a plant on the east side of the trial on August 28. Samples were air dried in a barn when daytime highs averaged 89˚F for 13 days, until no further weight loss was observed. The third biomass sample was taken on 28 September and air dried until no further weight loss was observed on 13 October. During drying of the third sample daytime high temperatures ranged from 51˚F to 76˚F and averaged 65 ˚F. No after frost sample was taken because only two days elapsed from the third sample to killing frost on 30 September.



Average air-dry biomass yield of Tropic Sun sunn hemp from samples harvested 30, 60, and 90 days after planting.

Discussion
Both soybean and sunn hemp are sensitive to cold and planting must be delayed until all danger of frost has passed. Both are also easily killed by the first fall frost. Soybean should be planted after the soil has warmed to 50°F and warm weather is forecast. A planting date after May 15 will reduce the risk of frost damage, but if the seed is in short supply and replanting after frost would not be possible, a late May or early June planting date is advisable. The air dry biomass production of the above-ground stems and leaves of forage soybean and sunn hemp was very similar, more than 5 ton/acre. Air drying the third sample of sunn hemp at cooler temperature may have slightly overestimated total biomass production.

Because of their cold sensitivity, these two legume green manure crops have only about 120 days of growing season available at the lowest elevations in the Great Basin. This prevents the use of these legume green manures for multiple cuttings of hay or in a double-crop system as in regions with a longer growing season. Green manure crops with more cold tolerance, such as winter rye, triticale, canola, oil radish, and oil mustard allow more flexibility in the growing season but would require supplemental nitrogen fertilizer for optimum biomass production. Production in the cooler months would also depend on availability of irrigation water.

Maturity group VII soybean cultivars were selected because vegetative growth was the objective, not reproductive growth resulting in seed production. Similarly, the sunn hemp flowered late in the season but did not set seed. Soybean should be planted into soil that has been pre-irrigated, rather than planted into dry soil and irrigated, to minimize crusting that could impede emergence. Depriving the soybeans of irrigation during mid to late July resulted in severe stress and probably reduced biomass production. Some plants wilted in the afternoon and recovered turgor by the next morning. Very little mortality was seen, and plants began to grow again and appeared normal when irrigation was restored on 3 August. The sunn hemp in this trial emerged well with flood irrigation immediately after planting.

Biomass yield can be improved by having adequate levels of phosphorus, potassium, and sulfur. The only nutrient applied in these trials was a foliar application of chelated manganese to the soybean cultivars in June after row closure. Using the "rule of thumb" value of 3.5 to 4 percent N in legume tissues (Clark, 2007) the above ground biomass produced by these soybean varieties could add from 418 to 453 lb N/acre to the soil. Using a value of 4 percent N for the sunn hemp biomass, the N production was approximately 28 lb N/acre at 30 days, 166 lb N/acre at 60 days, and 429 lb N/acre at 90 days.

Both the soybean and sunn hemp green manure crops were inoculated with the strain of bacteria specific to the crop. Different rhizobium bacteria nodulate alfalfa, beans, peas, and other legumes and will not suitably nodulate soybean or sunn hemp. Whenever a new legume is planted in a soil where a legume of that genus was not grown before, it is necessary to inoculate the seed with the correct strain of bacteria. Suitable inoculant is generally available with the seed from the seed vendor. In subsequent years it is cheap insurance to inoculate the seed to be sure of having adequate nodulation to fix nitrogen for optimum growth of biomass as soon as the seedlings begin to produce lateral roots.

Cottontail rabbits were numerous at Great Basin PMC during the sunn hemp growth, and deer tracks were often found passing within a few feet of the sunn hemp plot, but no feeding damage was observed. A few lygus bugs were seen on the new growth at the tops of the plants but no malformed flowers or injury from lygus feeding was observed. A few fasciated plants were seen, but it is not known if this is inherent in the cultivar, a result of lygus feeding injury, or a pathogen. Although plants began flowering about 60 days after planting, no seed pods were seen, and no pollinators were seen visiting the bright yellow flowers.

Most *Crotalaria* species contain alkaloids that are poisonous to livestock. The cultivar Tropic Sun has a lower level of alkaloids and a preliminary report (Rotar and Joy, 1983) suggested it may be suitable for forage, although it becomes too stemmy to be quality forage after 6 weeks (Mansoer, Reeves, and Wood, 1997).

No regrowth was seen on the areas that were clipped at 30 and 60 days, but the stems of those plants were cut off at the ground level. Following a forage harvest, a taller stubble height might allow regrowth from axillary buds, but that was not tested at this site.

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