Velvet Bean (*Mucuna pruriens* var. *utilis*) a Cover Crop as Bioherbicide to Preserve the Environmental Services of Soil

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1. Introduction

Cover crops have been used as green manure since the Zhou dynasty (1134-247 BCE) in China. Later on, Greeks and Romans used legumes widely as part of their crops. Pliny, Virgil, Theophrastus and other philosophers (Cato, Varro, Columella and Palladius) wrote about the use of legumes as cover crops (Allison, 1973; Tivy, 1990; Winiwarter, 2006). Also, the Codex Vergara and Florentine Codex,-the most comprehensive textual encyclopedia of Aztec soil knowledge shows the role of application of soil amendments as practice to maintaining or increasing soil fertility (Williams, 2006). The use of legumes as associated or rotation crops or their cultivation as green manure was a strategy to replenish the soil nitrogen that had been used up by crops and to provide organic matter necessary to maintain the soil's physical and chemical conditions favourable for sustained crop production (Mulvaney et al., 2009).

Since the 1940's, economic policies based on the wide availability of cheap fossil fuels and chemical fertilizers encouraged the adoption of maximum-yield production systems, without any consideration of their sustainability or their environmental impact. As a consequence, the use of and research on cover crops, crop rotation and other traditional soil management practices were radically abandoned. However, fertilizers have not replaced the function of organic matter and other management practices; rather, soil erosion and toxic waste have disproportionately increased with the increase of agricultural production, leading to a progressive decline in crop productivity due to soil degradation and contamination of aquifers and surface water bodies. Land productivity has also declined due to increasing problems of weed infestation, pests and diseases (Cox &Atkins, 1979; Mulvaney et al., 2009; Yates et al., 2011).

Farmers in tropical regions use slash-and-burn farming as a common soil-use method. This approach can be sustained under long fallow periods, low population density and strictly for subsistence demands. However, the much higher density of modern populations and their exacting demands for resources make the approach to crumble and decay: Soils start degrading and herbicides, pesticides and chemical fertilizers are needed to sustain crops, with the ensuing and well known economic and environmental problems (Greenland, 1975; Cox & Atkins, 1979; Bandy et al., 1993).

With the widespread use of chemical fertilizers, cover crops and green manures are now disregarded as inefficient, expensive nitrogen supplies, without due consideration of their various biological benefits. Despite the dominant technological trend, some farmers in the tropical regions of Latin America have developed and promoted, on their own initiative, the use of Velvetbean or Picapica mansa (*Mucuna spp*.) as a means to sustainably use clear-cut fields. This way, farmers are able to sustainably and inexpensively grow subsistence and other various crops thanks to the biocontrol of weeds, pests and diseases and the preservation of soil fertility that are provided by using Velvetbean for crop rotation or intercropping (Flores, 1989; Buckles & Perales, 1994; Ortiz-Ceballos & Fragoso, 2004). Clearly, the cover crop concept has to be considered in a broadest sense and not only as a rudimentary way to add nitrogen to the soil.

The Velvetbean technique is becoming better known and has been evaluated by researchers, but no attempts to improve, further develop and disseminate it have been made. Modern criteria and methods to comparatively evaluate the benefits provided by different cover crops are lacking and the properties of *Mucuna* cultivars are still unknown.

2. Green manure and cover crop concepts

Several authors have defined green manure as herbaceous, shrubby or woody plant material that is grown either *in situ* or *ex situ,* and is then incorporated into the soil when still green or before reaching full maturity to maintain and/or improve soil fertility (Allison, 1973; Hauck, 1977; Yost & Evans, 1988; Sarrantonio, 1991). Several different forms to apply green manure to soil do exist:

a. Simultaneous cut and burial
b. Cut and scattering over the soil surface
c. Incorporation of material produced and harvested at some other field
d. Cut to prepare soil improvers and compound manures ("compost")

Cover crops are plant species cultivated as rotation crops or intercropped with annual or perennial crops to control weeds, nutrient loss and weathering, to protect the soil by preventing erosion and to supply biological nitrogen for crop or livestock nutrition (Purseglove, 1987; Yost & Evans, 1988; Sarrantonio, 1991).

However, green manures and cover crops are often considered as expensive, inefficient production elements (as nitrogen sources), disregarding the various environmental services they perform. Farmers, through their long-standing relationship with plants, have incorporated green manures and cover crops into their farming systems as a strategy for sustainable production, as they provide a means for the biocontrol of weeds, pests and diseases and for maintaining soil fertility. For these reasons, the cover crop concept has to be considered in a broadest sense and not only as a rudimentary way to add nitrogen to the soil. This comprehensive concept has been adopted in this work to use velvetbean as bioherbicide.

3. Historical use of cover crops and green manures

Interest to preserve soil fertility for crop production through the use of legumes as cover crops or green manures has been known since the origin of agriculture (Allison, 1973; Tivy, 1990; Sarrantonio, 1991; Winiwarter, 2006; Williams, 2006).

In China and Japan, the use of cover crops and green manures -mainly legumes- that were incorporated directly to the soil as soil improvers or used as rotation, associated or relay crops to support cereal crops has been documented since over 3000 years ago. It was also a common practice in Greece, Rome and Mesoamerica, under conditions of cheap labour, water restrictions and lack of inorganic fertilizers (Allison, 1973; Hauck, 1977; Winiwarter, 2006; Williams, 2006). By 1976, the surface area cultivated with green manures in China was nearly 6.6 million hectares (Hauck, 1977).

Such soil conservation and management practices developed by ancient agricultural civilizations were adopted and remained virtually unchanged in most of the agricultural regions of the world until 1840 when the practice of soil fertilization with guano and superphosphates began. However, widespread use of those materials did not start until 1900. In Germany, the chemical fertilizers industry began in 1850, incentivized by Julius von Liebig's work on fertility and plant nutrition. Overall, it was not until 1945 when the intensive use of synthetic fertilizers in agriculture and livestock raising began in the USA, Europe and Australia (Allison, 1973; Tivy, 1990; Mulvaney et al., 2009).

Traditional agriculture in the USA, Europe, Australia and Mesoamerica consisted of prairie rotation with a wide variety of cereal, root and legume crops, which allowed for a diversity of ploughing methods and nutritional demands over the three to six years rotation cycle. The advantages of this were: a) protection against price volatility and losses due to pests and disease; b) better use of the land, according to climate conditions through the year and, perhaps more importantly, c) maintenance of soil fertility. Thus, by stabilizing the content of nitrogen-rich organic matter, the growth of beneficial microorganisms was promoted and the soil's physical and chemical conditions were improved leading to a sustained crop production (Mckee, 1948; Cobb, 1950; Allison, 1973; Tivy, 1990).

Until then, agricultural research was focused on optimizing and explaining the benefits derived from prairie and crop rotation, as opposed to continuous cultivation, in terms of fertility maintenance, nitrogen supply, improvement of the soil's physical and chemical conditions, and biocontrol of weeds, pests and diseases (Weindling, 1946; Snyder et al.,1959; Mulvaney et al., 2009). Such traditional system integrating agriculture and livestock raising prevailed until the mid twentieth century. However, with the adoption of synthetic nitrogen fertilizers and herbicides, that line of research was abandoned and the use of cover crops, crop rotation and other similar soil management techniques were discontinued, as yields obtained with those were two to four times lower than those obtained with fertilizers (Allison, 1973; Greenland, 1975; Tivy, 1990; Mulvaney et al., 2009; Yamada et al., 2009).

Modern intensive agriculture is characterized by the use of sophisticated technologies, heavy investment of input capital, high crop and animal yields and maximum efficiency.

This demands a large energy input either directly in form of human and animal labour, fossil fuels and electricity, or indirectly in the form of fertilizers, herbicides, pesticides, seed, water and other agrochemicals (Tivy, 1990). The intensification of agriculture and livestock raising relies on larger inputs, the most important of which are those related to plant and animal nutrition. Crop yields depend on fertilizers, pesticides, herbicides and growth promoters; animal yields depend on nutrient-rich fodder (Tivy, 1990; Mulvaney et al., 2009; Yamada et al., 2009).

The intensification of modern agriculture began some 40-60 years ago as a result of scientific and technological developments collectively referred to as the "Green Revolution". The Green Revolution started immediately after the Second World War and was characterized by: a) increased mechanization of soil management, b) increased use of fertilizers, insecticides, pesticides, herbicides, veterinarians and other non-essential additives, and c) a fast and widespread development of genetic improvement programs for plant and animal species (Wade, 1974; Greenland, 1975; Tivy, 1990; Mulvaney et al., 2009; Yamada et al., 2009; Yates et al., 2011). Those scientific and technological developments were rapidly and widely adopted in the USA, Europe and Australia, while socio-economic and cultural factors limited their use in Latin America, Africa and Asia (Greenland, 1975; Pimentel et al., 1980; Yamada et al., 2009). This technological phenomenon was accompanied by a high specialization in production and the separation of agricultural and animal production (Greenland, 1975; Tivy, 1990; Mulvaney et al., 2009).

Such intensification has imposed a considerable cost on the environment, due to: a) increased soil erosion due to the soil exposure to weather effects; the ensuing increased silting has reduced the efficiency of impoundments and irrigation channels and has impaired navigation, with a concomitant loss of nutrients and water quality; b) ecosystem degradation and destruction, as well as drastic changes in the physical environment directly caused by farming activities, followed by the decimation or loss of plant and animal species; c) the use of large amounts of fertilizers has polluted water bodies and aquifers with nitrates and phosphates; d) pesticides have fostered the development of resistance and persistence in pests and pathogens and have affected wild species, particularly birds (Cox & Atkins, 1979; Pimentel et al., 1980; Tivy, 1990; Mulvaney et al., 2009). The ensuing dilemma is that efforts to modify one part of the farming environment have degraded other equally important components: natural ecosystems (Tivy, 1990).

4. Persistence of the slash-and-burn system in maize

The slash-and-burn system has been practiced for millennia in many tropical or warm-humid regions in Latin America, Africa and Asia. Evidence suggests that this system began in New Guinea some 5,000 years BCE. The slash-and-burn system is currently used in approximately 800 to 1,400 million hectares globally, some 11 to 25 million of which are actually cultivated every year, providing basic staples for the subsistence of over 300 million people inhabiting those regions (Mabberley, 1992). A vast literature has been produced on this subject (Greenland, 1975; Cox & Atkins, 1979; Lal, 1987; Tivy, 1990; Mabberley, 1992; Bandy et al., 1993; Willis et al., 2004; Eastmond & Faust, 2006), but a brief synthesis of the main features of this farming system seems appropriate here.

This traditional farming system varies as a function of: a) climate, soil and vegetation; b) farmers' background; c) population density, and d) demand on available land. The system is applied on small clear-cut parcels, sometimes separated one from the other as farmers only have manual tools such as axe, machete and sowing stick available, which restricts the size of the area that can be clear-cut and cultivated every year. Land is clear-cut during the dry season of the year and only partially, as some tree species that facilitate vegetation regeneration during the fallow period are left standing. The dry plant material is burned before plantation starts. Fire is a cheap and powerful tool that humans have been using for over 1.0 – 1.7 million years to quickly and efficiently clear the land, a process which also allows for: a) pest and disease control, b) slowing down the germination of weeds' seeds, c) accelerating the microbial populations growth, d) increasing mineralization of organic nitrogen and other nutrients stored in ashes, and e) lowering the crops' costs.

Nutrients stored in ashes and on the soil surface only last for two to three years of continuous cultivation as they are quickly depleted. The nutrients amount and quality depend on the site potential. Weeds are controlled either manually or using simple tools. A variety of crop species are grown, including maize, rice, manihot, yam, taro, bean, pumpkin, hot pepper, sweet potato and others. Cultivation techniques vary in their spatial distribution, including crop rotation, association or intercropping, which allow for production diversification, an optimal use of land and protecting the soil from the destructive effects of weather. Crop yields rapidly decrease after two to four years of cultivation, due to nutrient depletion, increase in hard-to-control weeds (such as *Imperata cylindrical*, *Sorghum halepense* and *Cyperus rotundus*) and damages by pests and diseases. As a consequence, a) fertilizers, herbicides and pesticides are required to sustain further cultivation, with well-known economic and environmental disadvantages, or b) the parcel has to be left to fallow for five to twelve years, or c) is abandoned.

When land is left under fallow, new vegetation develops from seeds stored in the soil's seed bank or arriving from the surrounding vegetation and from shoots emerging from previously present species, through a successional process the course of which varies as a function of soil type, climate, cultivation history, soil degradation and presence of still standing species. Second-growth vegetation takes up the few nutrients that still remained in the top soil and that are leached down to lower horizons, to bring them back to the surface in the form of organic matter, thus closing up the nutrient cycle, humus accumulation, weed suppression and the control of pests and diseases. Since ancient times humans have collected and cultivated a number of useful wild species from second-growth vegetation, some of which are commercially valuable nowadays (e.g., mahogany, cedar, rubber, banana, cocoa, palms, etc.). However, as farmer populations in tropical regions become larger and impose more exacting demands on natural resources, the slash-and-burn system tends to break down and become unsustainable, due to the loss of soil fertility and increased erosion resultant from the intensification and protraction of continuous cultivation. In addition, populations immigrating from other environments are often unfamiliar with or do not follow the farming systems traditionally practiced by native populations of tropical regions, which leads to more severe and faster depletion of resources. These factors lead to a shortening of the fallow period which breaks the nutrient cycle down and disrupts the biological control of weeds, pests and diseases.

Nowadays, the slash-and-burn farming system is berated for its impacts on the biosphere as it contributes with over 20-30% of the global CO_2 emissions causing the greenhouse effect

(Kremen et al., 2000). In addition, tropical rain forests harbour a wealth of biological diversity the destruction of which entails a significant loss of plants and animals with actual or potential value for humanity.

5. Velvetbean or "Picapica mansa" (*Mucuna spp.)* cover crop as a means for a sustained use of soil

As discussed in the previous sections, legume cover crops have recently drawn attention in the USA, Europe, Australia, Latin America, Africa and Asia due to a) the unavoidable depletion of fossil fuels and the increase in the cost of nitrogen fertilizers; b) biosphere degradation caused by traditional intensive farming systems; and c) the unsustainability of the slash-and-burn system due to population growth. In addition, cover crops are also attractive for biocontrol of weeds, pests and diseases and for protecting the soil from erosion and weathering (Allison, 1973; Greenland, 1975; Hauck, 1977; Reddy et al., 1986; Lal, 1987; Yost & Evans, 1988; Smyth et al., 1991; Carsky et al., 2001; Elittä et al., 2003; Kaizzi et al., 2004; Baijukya et al., 2005; Yamada et al., 2009; Mulvaney et al., 2009; Olorunmaiye, 2010; Odhiambo et al., 2010; Odhiambo, 2011).

Several authors have described various farming systems including legume cover crops in various tropical regions of the world. Those crops are used for rotation, intercropping or associated with rice, maize, plantations, root, tuber crops, tomato, sorghum, cassava, etc. (Whyte et al., 1955; Gray, 1969; Warriar, 1969; Kay, 1985; Yost & Evans, 1988; López, 1993; Flores, 1989; Kaizzi et al., 2004; Wang et al., 2009; Olorunmaiye, 2010).

5.1 Characteristics of *Mucuna* spp.

The genus *Mucuna*, belonging to the Fabaceae family, covers perhaps 100-150 species of annual and perennial legumes. The study taxon (*Mucuna* spp.) is known by various names in different tropical regions of the world: "Picapica mansa" (Veracruz, México) and "Nescafé" (Tabasco, México), as it is occasionally used as coffee substitute; "frijol de abono" (manure bean in Honduras); "frijol de mula" (mule's bean in Guatemala); "haba de terciopelo" (velvet broadbean in Puerto Rico); "poroto aterciopelado" (velvetbean in Argentina); "ojo de venado" (deer's eye in Spain); "haricot velouté" (Francia); "makhmali sem" (India); "Stizolobia" (Italia); velvetbean" (USA); and banana stock pea (Australia).

This legume is native to Malaysia, South China, China and India but nowadays is widely distributed in many tropical regions. Cultivated and wild varieties from America and Africa were originally introduced and propagated by humans along various commercial routes. The main differences among cultivated species are in the character of the pubescence on the pod, the seed colour, and number of days to harvest of the pod. So far, improved cultivars have only been produced in: a) Australia (White, Mauritius, Black Mauritius, Somerset, Marbilee, Smith and Jubilack), b) USA (Georgia, Alabama, Osceola, Yokohama and Florida, and c) Zimbabwe (Bengal, White Stigless, SES 30, SES 45, SES 68 SES 74 and SES 108). Throughout its distribution range, the species has also been given various scientific names, among them: *M, deeringianum* Bort., *M. utilis* (Wall) Baker ex Burck, *M. pruriens* (L.) DC, *M. cochichinensis* (Lour.) Burk, *M. nivea* (Roxb.) Kuntze, *M. capitata, M. aterrima* Piper & Tracy, *M. Hassjo*, *M. diabolica, M. cinerum, M. haltonii,*and *M. sloanei* Fawcett & Rendle, some of which are just synonyms but others may represent valid names referring to different taxa

(Whyte et al., 1955; Duke, 1981; Göhl, 1982; Kay, 1985). In addition, an argument among taxonomists on whether the taxon is *Mucuna* or *Stizolobium* still exists; some recognize morphological features that set them apart while others maintain that they are synonyms (Whyte et al., 1955; Duke, 1981; Göhl, 1982; Kay, 1985; Pugalenthi et al., 2005; Zaim et al., 2011).

The genus *Mucuna* includes species of annual and perennial plants with vigorous indeterminate growth that, under favourable conditions, can produce vines 3 to 18 m long (occasionally longer). These plants might grow under short days, with a life-cycle length ranging from 120 to 330 days. Leaves are trifoliate, with oblique lateral folioles 5-20 cm long, 3-15 cm wide. Flowers white to purple, four to six flowers arranged in hanging racemes 2-3 cm long, flowers with wing and keel 3-4 cm long, much longer than the 2 cm long banner. Pods are 5 to 15 cm long, 1-2 cm wide, with three to six seeds, covered by a velvety pubescence, black to white or absent. Seeds are 1-2 cm long, 5-6 cm thick, colour cream, bright black or mottled brown, hilum 3-5 mm long and long aril. Numerous roots 7-10 m long, with abundant nodules near the soil surface. The plants accumulate between 2.2 and 10.9 t/ha of dry biomass and produce between 0.24 and 6.12 t/ha of seed (Duggar, 1899; Tracy & Coe, 1918; Scott 1919; Watson, 1922; Whyte et al., 1955; Duke, 1981; Göhl, 1982; Kay, 1985; Purseglove, 1987; Pugalenthi et al., 2005).

Mucuna grows better in warm humid climates, with annual precipitation from 3.8 to 31.5 dm and temperatures between 18.7 and 30 °C; night temperatures of 21 °C promote flowering. The plants are sensitive to frost during the growth season, drought tolerant once established but do not tolerate excess moisture. They grow on various soil types, with pH between 4.5 and 7.7 (Whyte et al., 1955; Duke, 1981; Kay, 1985; Pugalenthi et al., 2005).

The dry weight composition of *Macuna* green forage, pods and seeds is as follows: a) Foliage: 10.8 to 23.5% protein; 2.1% fat; 48.6% nitrogen-free extract; 19.3% fibre; 14.9% ash; 10.7% digestible protein; 49.6% digestible carbohydrates; 63.4% total digestible nutrients; b) dry pods: 10.0% moisture; 13.4 to 18.1% protein; 13.4% digestible protein; 73.8% total digestible nutrients; 13.0% raw fibre; 4.4% fat and 4.2% ash; c) Seeds: 10.0 % moisture; 19.0 to 37.5% protein; 4.7-9.0% fat; 51.5% nitrogen-free extract; 81.7% total digestible nutrients; 5.3-11.5% raw fibre and 2.9-5.7% ash (Duke, 1981; Göhl, 1982; Kay, 1985; Pugalenthi et al., 2005). The studies on mineral composition of *Mucuna* seeds reveal that they contain potassium, calcium, iron, manganese, zinc, copper, magnesium, phosphorous and sodium with 778-1846, 104-900, 1.3-15, 0.6-9.3, 1.0-15.0, 0.3-4.3, 85-477, 98-498 and 12.7-150.0 mg/100 g, respectively. Among the amino acids found in seeds, the aspartic and glutamic acids are found to be predominant (8.9-19 and 8.6-14.4%, respectively), whereas the levels of other amino acids are found to be low (Pugalenthi et al., 2005).

The seeds of *Macuna* also contain many antinutritional factors such as total free phenolics, tannins (3.1-4.9%), L-Dopa (4.2-6.8%), lectins (0.31-0.71%), protease inhibitors (trypsin and chymotrypsin), phytic acid, flatulence factors (Oligosaccharides), saponins (1.15-1-31%), and hydrogen cyanide (58 mg/kg), alkaloids (Pugalenthi et al., 2005).

Seeds are used for human consumption in some parts of Africa and India, which is just reasonable given their high contents of protein and minerals and low fibre content. For this same reason, their use as part of the diet of monogastric animals is also attractive, although in limited amounts due to their alkaloid contents. Experiments showed that rats fed with “picapica mansa” seeds died after 72 hr, while pigs and milking cows fed with seed-rich diets showed an impoverished quality of fat and milk, respectively (Duggar, 1899; Duke, 1981; Göhl, 1982; Kay, 1985; Pugalenthi et al., 2005). Thus, *Mucuna* seeds seem to constitute a valuable but still underutilized resource in tropical regions as the seed’s toxic compounds have first to be eliminated or reduced either through conventional methods or by breeding *ad hoc* cultivars (Pugalenthi et al., 2005).

Mucuna is resistant and tolerant to many pests and diseases, probably due to its content of 3-4-dihydroxyphenylalanine (L-Dopa) and N,N-Dimethyltryptamine (DMT) in leaves and seeds, which provide a chemical barrier to the attack of insects and small mammals. However, it is severely attacked by a) fungi such as *Cercospora stizolobii, Mycospharella cruenta, Phyllostica mucunae, Phymatotrchum omnivorium, Phytophthora dreschsleri, Rhizoctonia solani, Sclerotium rolfsii* and *Pestalotiopsis versicolor*; b) bacteria such as *Xanthomonas stizolobiicola, Pseudomonas stizolobii, P. syringae* and *Striga gesnerioides*; c) virus: Bean common mosaic virus (BCMV), Bean pod mottle virus (BPMV), Bean yellow mosaic virus (BYMV), Cowpea mosaic virus (CoMV), Soybean mild mosaic virus (SMMV), Soybean mosaic virus (SMV), Soybean stunt virus (SSV), True broad bean mosaic virus (TBBMV), Tobacco ringspot virus (TRV), Tobacco streak virus (TSV), Watermelon mosaic virus-II (WMV-II) and Velvetbean severe mosaic virus (VbSMV) as new species of genus *Begomovirus*; and d) nematodes: *Meloidogyne thamesi, M. hapla, M. incognita* and *M. javanica* (Duke, 1981; Kay, 1985; Zaim et al., 2011).

5.2 History of the use of *Mucuna*

Since some 50 yr ago, farmers in some regions of Latin America have developed and disseminated the use of “Velvetbean” as rotation or associated crop to make a continuous use of clear-cut lands for production of subsistence crops (Duke, 1981; Kay, 1985; Triomphe 1996; Ortiz-Ceballos & Fragoso, 2004). Little is known about the introduction of “Velvetbean” to Latin America. Bort (1909) and Duke (1981) claim that this species was initially introduced to the USA in 1876, where it was cultivated and improved and, later on (in the 1920’s), was introduced to Mexico and Central America by banana companies. However, the question remains whether it may have been introduced earlier than that through some other commercial routes between Asia and other Latin American countries, as it has happened with other species.

“Velvetbean” was grown in Southern USA because it constituted an important resource as a protein-rich seed forage for feeding cows (for meat and milk production) and pigs, as well as for the nitrogen supply it provided when used as a cover or rotation crop, to maintain the fertility of land cultivated with cereals, cotton and citric crops. For these reasons, the development of short-cycle cultivars through artificial selection and genetic improvement of naturalized and newly introduced varieties was promoted (Whyte et al., 1955; Duke, 1981; Bort, 1909). By 1918, over three million hectares were cultivated with “Velvetbean” in Florida, Mississippi, Alabama and Georgia, using technologies developed in research centres and based on its use as green manure (Tracy & Coe, 1918; Scott, 1919; Watson, 1922; Bort, 1909). The use of “Velvetbean” decreased in the early 1920’s but remained important until the mid 1940’s. Afterwards, the crop just disappeared from agricultural production statistics as a consequence of the increase in the use of nitrogen fertilizers and the cultivation of soybean as a commercial crop.

This species has also been grown in the tropical regions of over 20 countries as cover crop or green manure, either as a rotation or associated crop, to maintain soil fertility, as forage and for biological control of weeds, pests and diseases, in association with crops such as maize, rice, sorghum, sugar cane, manihot, banana, coconut, citric crops, coffee, rubber and prairies (Whyte et al., 1955; Pugalenthi et al., 2005).

6. Advantages and disadvantages of the use of *Mucuna*

At present, the use of *Mucuna* is a traditional technology that is becoming better known, described and evaluated by researchers both, in experimental fields and in farmers' parcels in various tropical regions of Latin America and Africa. In the following paragraphs, we present a summary review of the advantages and benefits that can be obtained in the biological control of weeds, pests and diseases and the maintenance of soil fertility by using *Mucuna* as a rotation or associated crop.

With regard to dry biomass accumulation, average yields of 7.9 ± 4.7 t/ha are obtained, with 19.0, maximum and 1.5 t/ha, minimum (Table 1).

Biomass (dry matter)	**Location**	**Reference**
2.9 - 7.3	Veracruz, Mexico	Eilitta et al. (2003)
18.0 - 19.0	Veracruz, Mexico	Buckles & Perales (1994)
3.4 - 5.3	Tabasco, Mexico	Ortiz-Ceballos et al. (2004)
2.0 - 3.9	Veracruz, Mexico	Ruiz & Laird (1964)
7.0 - 10.7	Manaus, Brasil	Smyth et al. (1991)
4.4 - 7.1	Florida, USA	Reddy et al. (1986)
3.1 - 8.3	Kaduna, Nigeria	Carsky et al. (2001)
7.0 - 16.3	Tela and Jutiapa, Honduras	Triomphe (1996)
10.6 - 12.4	Bulegeni and Kibale, Uganda	Kaizzi et al. (2004)
2.0 - 13.8	Kaduna, Nigeria	Franke et al. (2004)
3.3 - 11.2	Hwedza, Zimbadwe	Whitbread et al. (2004)
1.6 - 9.8	Limpopo, South Africa	Odhiambo (2011)
3.7 - 9.8	Limpopo, South Africa	Odhiambo et al. (2010)
1.5 - 8.7	Southern, Benin Republic	Vanlauwe et al. (2001)
7.4 - 10.2	Florida, USA	Wang et al. (2009)
9.9 - 10.6	Vihiga, Kenya	Kiwia et al. (2009)

Table 1. Biomass yield (t/ha) of different cultivars of Velvetbean (*Mucuna pruriens* var. *utilis*) in the system rotation with maize.

Seed yields average 2.6 t/ha (maximum 6.12 t/ha and minimum 0.24 t/ha). Accumulated dry biomass contributes an average of 189.3 ± 112.2 kg/ha (range 3.0 - 430 kg/ha) of inorganic nitrogen when is incorporated into the soil (Table 2). This wide variation can be explained by the influence of the sowing season and density, as well as the phenological stage at the time of incorporation which influences the biomass content of organic carbon, nitrogen and structural carbohydrates (Odhiambo, 2011). Temperature, humidity and actual evapotranspiration in the habitat are also important factors influencing the rate of biomass accumulation and its decomposition by soil microorganisms. The best time to incorporate the cover crop into the soil is at the onset of pod filling, when some 50 to 75% of the growth cycle has been completed, as maximum yields of dry biomass and accumulated nitrogen can be obtained this way (Allison, 1973; Gerónimo et al., 2002).

Nitrogen	Location	Reference
272 - 316	Tela and Jutiapa, Honduras	Triomphe (1996)
68 - 111	Veracruz, Mexico	Ruiz & Laird (1964)
130 - 330	Tabasco, Mexico	Ortiz-Ceballos et al. (2004)
100 - 190	Florida, USA	Reddy et al. (1986)
168 - 254	Manaus, Brasil	Smyth et al. (1991)
50 - 147	Veracruz, Mexico	Eilitta et al. (2003)
43 - 279	Limpopo, South Africa	Odhiambo (2010)
3 - 279	Limpopo, South Africa	Odhiambo et al. (2011)
150 - 430	Bulegeni and Kibale, Uganda	Kaizzi et al. (2004)
50 - 150	Bukoba District, Tanzania	Baijukya et al. (2005)
127 - 281	Kaduna, Nigeria	Carsky et al. (2001)
101 - 348	Hwedza, Zimbadwe	Whitbread et al. (2004)
22 - 193	Southern, Benin Republic	Vanlauwe et al. (2001)
190 - 262	Florida, USA	Wang et al. (2009)
305 - 329	Vihiga, Kenya	Kiwia et al. (2009)

Table 2. Nitrogen supply (kg/ha) of Velvetbean (*Mucuna pruriens* var. *utilis*) evaluated through the rotation with maize.

In some cases, increases (from 2.2 to 3.8%, for example) in the soil organic matter content have been observed as the age of the *Mucuna*-maize rotation system increases and the soil's chemical conditions are also improved. However, in some cases, no or little significant increases in organic matter content have been found, probably because the time when the rates of organic matter accumulation and decomposition reach an equilibrium is not known and also perhaps because the seasonal effects of weather and soil conditions on organic matter decomposition are not taken into account when the sampling scheme is designed (Triomphe, 1996; Gerónimo et al., 2002; Odhiambo, 2011). Barthès et al. (2004) studied changes in soil carbon (0-40 cm) in a soil sandy loam Ultisol in Benin (Africa), which involved a 12-experimentation on three maize cropping systems under manual tillage. In traditional no-input cultivation, mineral fertilized and association with Velvetbean changes in soil carbon were -0.2, +0.2 and +1.3 t C/ha/yr, with residues carbon to 3.5, 6.4 and 10.0 t/ha/yr, respectively. The carbon originating from maize and Velvetbean in litter-plus-soil represented less than 4% and more 50% of both total and overall residue carbon, respectively.

In those experiments where a significant increase in organic matter was observed, the soils also increased 20 to 30% in moisture content, and showed a higher cation exchange capacity, lower pH, lower apparent density and a reduction in micronutrient recycling. At the same time, with the use of *Mucuna*, reductions in the damage and mortality caused by *Pythium, Rhizoctonia* and *Fusarium* on maize seedlings have been documented, probably due to the type of organic matter that is incorporated into the soil, the effects of this on the soil's microclimate and/or its allelopathic effects (Versteeg & Koudokpon, 1990). Rotation of *Mucuna* with maize or banana crops reduces *Radopholus similis*, *Criconemella*, *Scutellonema*, *Melodogyne* and root-knot populations, but increases those of *Helicotylenchulus, Rotylenchulus*, *Rhabditidae*, *Cephalobidae* and *Pratylenchus* (Watson, 1922; Reddy et al., 1986; Figueroa et al., 1990; Blanchart et al., 2006).

Also, *Mucuna* in a cropping system modified the structure, composition, diversity and interactions of soil biota (earthworms, millipedes, centipedes, Coleoptera adults, Diptera larvae and Isopoda) that can promote soil structure and nutrient availability (Ortiz-Ceballos & Fragoso 2004; Blanchart et al., 2006; Ortiz Ceballos et al., 2007a; Ortiz Ceballos et al., 2007b).

Continuous cultivation of maize on slope-side parcels increases splash and sheet erosion, with soil losses of 127 t/ha/yr, or even as high as 200-3600 t/ha/yr. A *Mucuna*-maize rotation system on 30 to 65% slopes had soil losses of 52.3 t/ha/yr and in a no-burn grazing system with *Mucuna* coverage, soil loss was only 3.9 t/ha/yr (López, 1993). Some evidence indicates that this crop grows well on acidic soils, that the development of its root system is influenced by the availability of phosphorus and magnesium and that its yield increases with soil pH (Halriah et al., 1991). Rotation or intercropping with *Mucuna* has promoted fertility restoration and improvement of the physical conditions of soils that had been compacted by heavy machinery or degraded after intensive slash-and-burn cultivation, thus allowing their reincorporation to food production (Hulugalle et al., 1986; Lal, 1987).

For its vigorous, explosive growth and its allelopathic effect, "picapica mansa" has shown to be effective in weed suppression, particularly gramineous weeds which compete for light, water and space with annual and perennial crops. This has been shown in parcels infested by *Imperata cylindrical*, *Paspalum fasciculatum*, *Striga hermonthica* and *S. Asiatica* and *Cyperus rotundus* in Africa (Whyte et al., 1955; Buckles & Perales, 1996; Tarawali et al., 1999; Akobundu et al., 2000; Udensi et al., 1999; Carsky et al., 2001; Chikoye & Ekeleme 2001; Whitbread et al., 2004; Kiwia et al., 2009; Odhiambo et al., 2010; Olorunmaiye, 2011). Thus, this practice reduces the costs of weed control and releases hand labour that can then be devoted to other productive activities (Versteeg & Koudokpon, 1990; Odhiambo et al., 2010; Olorunmaiye, 2011). Planting distances that have been effective for weed control are 1.0 and 1.5m equidistant, equivalent to sowing some 15 kg of "picapica mansa" seed per hectare or some 15,000 – 16,000 plants/ha (Versteeg & Koudokpon, 1990). This provides an ample potential for the restoration of the 11 to 22 million hectares that have been infested by *Imperata cylindrica* in Indonesia (Tempany, 1951; Coomans, 1976). For example, Tarawali et al. (1999) document that, in the southern Benin Republic, *Mucuna* raised the interest of 3000 farmers (1988-1993) mainly for controlling *Imperata* and the numbers testers of the innovation rose up to 10000 farmers by 1996.

Finally, "picapica mansa" seems to be tolerant to the attack of pests and diseases due to its content of toxic secondary metabolites, and is able to outcompete weeds partly due to the production of allelopathic compounds (Duke, 1981; Kay, 1985). However, a survey conducted in tropical regions of developing countries showed only a limited acceptance of using cover crops as green manure; most of the advantages recognized through the survey were of agronomic character, while the disadvantages were mostly economic (Yost & Evans, 1988). In fact, economic hardships lead farmers to be far more concerned about having more land available to produce more subsistence crops to feed a larger population than about preserving soil fertility (Yost & Evans, 1988; Flores, 1989; Versteeg & Koudokpon, 1990). Water competition with the main crop, an increase in hand-labour and costs and the fact that, sometimes, its use is not profitable due to the low price of chemical fertilizers, have been identified as additional disadvantages (Warriar, 1969; Gray, 1969; Yost & Evans, 1988).

Some agronomic disadvantages of using "picapica mansa" are that it: a) is susceptible to burn during the dry season of the year, when grown in the vicinity of parcels managed by slash-and-burn; b) provides shelter for poisonous snakes and rats; c) is defoliated by rabbits, and d) attracts bean slugs *Sarasinula plebeia* Fischer (Versteeg & Koudokpon, 1990; Buckles & Perales, 1996). When legume plants are grown in association or intercropped with maize, a reduction in maize yield often occurs during the first cycle, the severity of such reduction depends on the legume species but also on its density and management. Finally, soil nitrogen losses through leaching and volatilization have also been recorded due to the absence of a crop able to absorb the nitrogen being released through decomposition, the immobilization of nitrogen coincident with the time when the crop makes the highest demands of this nutrient or to the increase in soil acidity (Triomphe, 1996). However, Jensen et al. (2011) indicates that the ability of the legumes to fix N_2 reduces emissions of fossil energy-derived CO_2 and results in lower N_2O fluxes compared to agroecosystems that are fertilizer with mineral N.

7. Effects of *Mucuna* spp. on maize yield

Farmers and researchers alike have found that the use of "picapica mansa", either as rotation crop or intercropped with maize, has beneficial effects on maize yields as a result of the several advantages and benefits described above. Thus, average yields of 3.2 ± 2.39 t/ha (range: 0.3 - 8.3 t/ha) have been reported, which compare favourably with the average yield of 2.2 ± 1.95 t/ha (range: 0.4 - 7.5 t/ha) that is obtained in monoculture (Table 3). The response of maize to improved fallows of mucuna was linearly related to the amount of biomass produced from the mucuna returned to the system. With an agronomic use efficiency of 11.3 kg grain/kg applied N and apparent N recoveries in the range of 25-53%, there were large quantities of N no utilised by the subsequent maize phase.

With *Mucuna*	**Without *Mucuna***	**Location**	**Reference**
1.0 - 1.5	1.2 - 1.3	Veracruz, Mexico	Eilittä et al. (2003)
1.9 - 4.5	1.4 - 2.5	Tela and Jutiapa, Honduras	Triomphe (1996)
2.6 - 3.2	0.8 - 1.8	Tabasco, Mexico	Ortiz-Ceballos et al. (2004)
4.5 - 5.1	3.8	Veracruz, Mexico	Ruiz J. & Laird (1964)
2.4	1.3	Manaus, Brasil	Smyth et al. (1991)
0.3 - 1.6	0.7 - 2.2	Veracruz, Mexico	Buckles & Perales (1994)
4.8 - 8.3	4.0 - 7.4	Limpopo, South Africa	Odhiambo et al. (2010)
6.3 - 8.2	2.3 - 4.2	Limpopo, South Africa	Odhiambo (2011)
0.7 - 0.9	0.7 - 0.8	Kwara, Nigeria	Olorunmaiye (2010)
3.8 - 7.0	2.9 - 6.3	Lomé, Togo	Sogbedji et al. (2006)
1.4 - 2.6	0.6 - 0.9	Yucatán, Mexico	Eastmond & Faust (2006)
1.4 - 4.2	1.4 - 4.3	Bukoba District, Tanzania	Baijukya et al. (2005)
0.7 - 2.5	0.6 - 1.0	Kaduna, Nigeria	Carsky et al. (2001)
0.8 - 1.0	0.4 - 0.5	Kaduna, Nigeria	Franke et al. (2004)
1.3 - 8.2	3.0 - 7.5	Bulegeni and Kibale, Uganda	Kaizzi et al. (2004)
2.2 - 5.8	1.2 - 2.6	Hwedza, Zimbadwe	Whitbread et al. (2004)
1.1 - 2.8	0.6 - 1.7	Southern, Benin Republic	Vanlauwe et al. (2001)

Table 3. Effect of the presence and absence of Velvetbean (*Mucuna pruriens* var. *utilis*) in maize grain yield (t/ha).

In hot, humid regions, the intensive cultivation of maize monocultures tends to break down and become unsustainable as the soil is degraded and/or herbicides, pesticides and chemical fertilizers are required to sustain the crop, with well-known economic and environmental problems (Cox & Atkins, 1979; Buckles & Perales, 1996; Bandy et al., 1993). By contrast, the *Mucuna* - maize intercropping or rotation system allows the affordable production of subsistence food staples as the system helps preserve soil fertility and biologically control weeds, pests and diseases.

8. Criteria for comparing and evaluating cover crops as bioherbicide

The general features that a cover crop should possess and the advantages of using this soil management practice are often listed. However, suitable methods to evaluate and compare cover crops are still lacking. Therefore, in this section we attempt to provide a summary view of the attributes that should be considered to evaluate and compare cover crops (Whyte et al., 1955; Allison, 1973; Sarrantonio, 1991; Versteeg & Koudokpon, 1990; Triomphe, 1996; Yost & Evans, 1988):

a. Growth rate. Species with vigorous, fast, indeterminate growth and high capability for interspecific competition can quickly protect the soil against weathering and erosion and possess good capacity to suppress weeds.
b. Biomass accumulation. The potential productivity of many species can be evaluated in terms of dry biomass production and nitrogen accumulation, both expressed in terms of kg/ha, which can then be related to the *in situ* evaluation of the Rhizobia capacity and effectiveness.
c. Carbon/nitrogen ratio (C/N). In general, if the C/N ratio of organic materials incorporated into the soil is higher than 30, nitrogen becomes immobilized. When the C/N ratio is lower than 20, nitrogen is released. The C/N ratio affects the action, rate and type of microorganisms involved in organic matter decomposition. However, temperature, humidity and actual evapotranspiration are also determining factors of decomposition rate in natural conditions.
d. Structural carbohydrates. The decomposition rate of organic materials and the action of soil microorganisms on them depend on the chemical nature of the plant tissues contained in the green manure that is incorporated into the soil and on their quality as fodder. Organic compounds such as lignin, hemicelluloses, cellulose and pectic substances are resistant to decomposition and/or digestion. The abundance of these materials influences nitrogen mineralization and organic matter digestibility. This is why models have been developed that predict decomposition rates or digestibility percentages based simply on the percentage content of lignin in foliage.
e. Seed quality and quantity. Plant species with high seed yields are always preferable as this facilitates their establishment and repopulation of new areas. Also important is the time, vigour and synchrony of germination to achieve a rapid establishment, features which are intrinsic to the seed and might be related to the presence of dormancy.
f. Resistance to the attack of pests and diseases. It is well known that wild, cultivated and some domesticated species release organic compounds that have allelopathic or toxic effects on herbivores and pathogens.

g. Other features. Finally, to choose a particular species as cover crop, attention should also be given to characteristics such as its adaptation to climate and soil conditions, low water and nutrient requirements, competition with the main crop, ease of management and low cost of incorporating it into the land's management plan.

9. Conclusions

Based on the above, we can conclude that *Mucuna* as bioherbicide may increase the functional properties of agroecosystem and allow a better agricultural ecosystem productivity: a) biocontrol of weeds and diseases, b) reduce the fossil energy used in the production of food, c) incorporation of OM and N into the soil (sequestration of carbon and lower emission of nitrous oxide), d) preservation of the soil biota, e) regulation of soil moisture and temperature, f) protection from soil erosion, g) *in situ* conservation and improvement of local maize cultivars, and h) sustained harvests.

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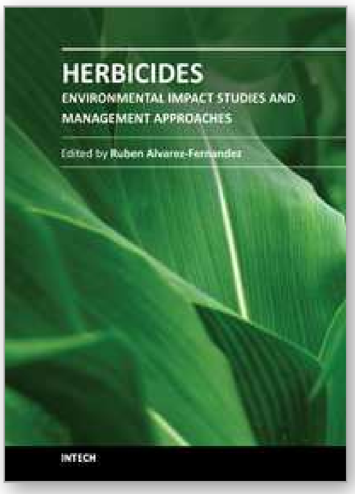

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Weeds severely affect crop quality and yield. Therefore, successful farming relies on their control by coordinated management approaches. Among these, chemical herbicides are of key importance. Their development and commercialization began in the 1940's and they allowed for a qualitative increase in crop yield and quality when it was most needed. This book blends review chapters with scientific studies, creating an overview of some the current trends in the field of herbicides. Included are environmental studies on their toxicity and impact on natural populations, methods to reduce herbicide inputs and therefore overall non-target toxicity, and the use of bioherbicides as natural alternatives.