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Green-Manuring for Increased Crop Production
(बढी उत्पादनको लागि हरियो मलको प्रयोग)

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Introduction (परिचय)

Green plants which are used as bio-fertilizer, plants and their parts (stem, leaves, twigs or roots) that are used into the soil by incorporating them or without any incorporation to improve soil health by adding nutrients contained in them and hence increasing to content of plant nutrients of soil with an goal of obtaining increased crop productivity and crop yields. There are wide range of green manuring plants, some are cultivated and some wildy grown in nature. Some green-manuring crops such as legumes develop nodules in stem, in roots and in some both. Nodule forming green manuring crops contain *Rhizobium* bacteria which has the ability of atmospheric dinitrogen fixation ($N \equiv N$) and produces N for the crop itself and to the soil. Other green-manuring plants which are wildy grown but rich in nutrient content such as Asuro, Khirro, Banmara, Titepati etc, also can supply plant nutrients after incorporation into the soil. These green manures can be added into the soil in in-situ culture or by bedding them in the soil from outside (ex-situ) and then incorporated. *Azolla* is a fern type water floating green manuring crop which has the ability of fixing atmospheric di-nitrogen (N_2) and can be used as green manure into the rice paddies.

Important Green Manuring Crops (केही प्रमुख हरियो-मल दिने बालीहरू)

1. Sunhemp (*Crotalaria juncea*) (सतई)

It is such a green-manuring crop which can supply plant nutrients to the crops and increased the crop productivity and crop yields. This crop can be cultivated as a sole crop

and then incorporated into the soil by ploughing or harrowing by a tractor. This Sunhemp (*Crotalaria juncea*) is incorporated into the soil in green condition so are often called green-manures. After its incorporation it supply nitrogen to the crop plants. Green-manures are very useful for crop such as maize, wheat and rice. They are grown as a sole crop and then incorporated into the soil at flowering stage.

Most leguminous crops bears nodules in their roots where *Rhizobium* bacteria is located and fix nitrogen from the atmosphere. Sunhemp is also a leguminous crop and can fix dinitrogen. In Nepal, Nitrogen (N) containing fertilizers are imported every year and it cost large amount of money and poor farmers cannot buy the fertilizers, some time they are not even available in cropping time. By the use of Sunhemp, crop plants can obtain required nutrients, mainly the nitrogen. Because of the intensive cropping, farmers grow 2 or 3 crops in a year and their soil is depleted with the plant nutrients. In this condition use of green-manures (Sunhemp) could be beneficial for the increased productivity. By the use of Sunhemp, the total amount of Nitrogen required by the maize crop can be cut down by 50 percent. Maize plants, in general, require 120 kg N/ha and we should give only 60 kg N from urea and the remaining 60 kg is supplied from Sunhemp. Use of Sunhemp is very cheap, easy planting and can be cultivated in large area of land. Sunhemp is itself manure so it does not need additional fertilizer application but small amount of phosphorus application on Sunhemp is beneficial. Generally, Sunhemp is grown as a sole crop and is incorporated into the soil in in-situ. For green-manure purpose seeds are sown @40-

45 kg/ha, for its seed production seed rate is 12-20 kg/ha and for fibre production 100-240 kg seeds/ha are sown. Sunhemp can be planted even in marginal land, it does not need fertile soils. It is cultivated not only in Terai but can be grown in Inner terai, foot hills and mid hills and mountain regions where soil moisture is available. Sunhemp crop is ready for incorporation into the soil in 40-70 days (near to flowing stage) and in two weeks the land is ready for crop planting. Sunhemp is very useful and beneficial in upland condition for maize crop compared to that of Dhaincha green- manuring. Research evidences prove that maximum of 177 kg N can be added to the soil in one season and 30% of this Nitrogen could be available to the succeeding maize crop which is equivalent to 115 kg urea. Remaining 95 kg should be supplemented from urea because maize needs a total of 210 kg urea (120 kg N/ha). Sunhemp is very beneficial and effective for maize.



Maize crop after Sunhemp incorporation at NMRP, Rampur, Chitwan, Nepal.



Sole cropping of Sunhemp at NMRP, Rampur, Chitwan



Sunhemp is incorporated at flowering time

Sunhemp Importance (सनईको महत्व)

- It supplies large amount of nitrogen to the soil. It accumulates soil organic matter after incorporation, other major and minor nutrients (micronutrients).
- It can produce large amount biomass, 20-30 t/ha only in 45-60 days.
- Due to its slow rate of decomposition and mineralization, it can supply plant nutrients steadily to the growing plants up to the maturity period.
- It improves physical properties of the soil. In addition it increases the efficiency of added chemical fertilizers.
- No losses of released nutrients by dinitrification, volatilization and leaching losses. Activities of micronutrients are increased.
- Its technology is easy and cheap. Seeds are obtained locally. Its cultivation is easy, local knowledge and skill is sufficient for its farming.
- Sunhemp is cultivated as a rotational crop which help retard/control of insect pests and diseases.
- Sunhemp leaves can be used as fodder for animals and stems are used as firewood after drying
- It is useful not only for one crop, but it can supply nutrients for the other succeeding crop because of its residual effects.
- Reports prove that 20-25% yield are increased in maize, nutrients supplied from Sunhemp are very cheap and easily available and high quality nutrients.
- This is a bio-fertilizer (green-manure) which do not replace the chemical fertilizer totally but decrease the demand of the chemical fertilizers, it is a supplementary type of fertilizer. Application of bio-fertilizer (Sunhemp)

along with chemical fertilizers could help increase crop productivity and improve soil fertility and soil health.

2. Nodulating Leguminous Crops (गिर्बादार कोशेवालीहरु)

These legumes develop nodules in their roots and *Rhizobium* spp contained in the root nodules fixes atmospheric dinitrogen and supplies to the host plant. The residue or the plant after harvest is incorporated into the soil and it provides sufficient amount of organic matter and nitrogen to the soil. These legume crops are usually grown for the specific purpose of capturing nitrogen from the air for the following crops. Crops such as clover, red clover, alfalfa, grain legume crops (Soyabean, cowpea, mungbean, blackgram etc) are grown as a sole crop, intercrop or relayed with other cereal crop and the *Rhizobium* contained in the root nodules fix atmospheric nitrogen. This nitrogen is supplied to the host crop, the legumes. Legumes crops such as alfalfa, clover are mostly solely grown and incorporated into the soil but grain legumes are incorporated into the soil only after the harvest of the crop but roots should not be uprooted from the soil which contain the *Rhizobium*. Farmers are suggested to grow grain legumes as a sole crop or as a relay or intercrop with maize. The *Rhizobium* bacteria that produce nodules on legumes species have a highly sophisticated crop recognition mechanism. They do not grow on just any old legumes. One type of Bacteria nodulates all the true clovers; still others are specific for soybean, for peas and vetches and for field beans. It is obvious that the first requirement for nodulation is the presence of appropriate bacteria in sufficient quantity to effectively nodulate the roots of the legume plants. These *Rhizobium* bacteria are isolated, develop and cultured in the laboratories

and further developed as bio-fertilizers which are used as inoculants to the concerning legumes crop or directly added into the soil before crop planting, which results in developing roots nodules and then fixing dinitrogen. In areas where legumes are never cultivated such inoculants should be applied directly into the soil or as seed should be inoculated. In poor soils, sole crop of legumes are cultivated and incorporated into the soil after flowering stage or at maturity. Application of Boron, molybdenum and phosphorus in small amount helps promote rapid N-fixation.

It develops nodules in roots or in stem or in some species in both parts which contain *Rhizobium* bacteria which fixes atmospheric di-nitrogen and supplies or adds nitrogen to the soil which helps increase soil productivity, and fertility for the longer period.

3. Dhaincha (ढेन्चा)

Scientific name of Dhaincha is *Sesbania sps.* and belongs to so many types, species and varieties. *Sesbania cannabina* is one of the important species which is available for cultivation in Research Stations, Govt. Farms and farmers in Nepal. *Sesbania rostrata* is another species of Dhaincha which was 1stly introduced in Agriculture Farm, Hardinath, Janakpur where its seed production programme was launched. *Sesbania rostrata* bears nodules in roots and stems (branches) where N-fixing bacteria "*Rhizobium*" are available and fix atmospheric dinitrogen. This species fixes more nitrogen than *Sesbania cannabina* because *cannabina* bears only root nodules. At least 2 t/ha of seeds can be produced from *rostrata* species whereas *cannabina* can produce only 1t/ha of seed. *Sesbania rostrata* can fix

nitrogen even in water logged condition because it bears stem nodules above the soil surface. This species can fix 267 kg atmospheric N/ha which is utilized by 1/3rd by the following rice crops and rest by the following crops in other years. So its residual effect is very effective compared to that of *S. cannabina*.

Dhaincha is a popular green-manuring crop for rice and it is reported that nitrogen gain by green manured Dhaincha is equivalent to 50-100 kg of fertilizer N (Lacsina *et al.*, 1987). Experimental results from Pakhribas Agricultural Center (PAC) showed that Dhaincha can be grown as a relay crop under maize without any effect in maize grain yield. Dhaincha relayed of the first and the second hoeing of maize and green manured increased rice grain and straw yields significantly compared to the control (no green-manures (Gurung and Shrestha, 1996). Reports also showed that green manuring of Dhaincha significantly increased available phosphorus levels in the soils.





Seed production of Dhaincha

Importance of Dhaincha (ढैचाको महत्व)

- Every year, we should import urea or other N-containing fertilizers from other countries and big amount of foreign currency has to be paid to purchasing the fertilizers. By the use of Dhaincha, total amount of urea-N can be cutdown at least by 50% to the rice crop, and hence can save our money.
- It can be easily grown in our condition, in Terai, Inner-terai, River valleys and basins, foot hills and middle mountains of Nepal. Its seeds are available in NARC Research Stations, DADO Offices (upon demand), and DOA Agriculture Centers. In 3-4 months, Dhaincha crop is ready for incorporation into the soil.
- Nutrients derived from Dhaincha are very cheap as compared to those of chemical fertilizers. Soil physical and biological properties are increased. Soil organic matter is added in larger quantities and it gives long term residual effect to the following crops.

- Enhancement of organic farming, high price of organic products in Nepal and abroad. No risk to human health hazards. It is environmentally friendly.
- Research evidences show that 21-25% yield increment observed in rice by the application of Dhaincha alone. Reports also prove that 50 kg of Dhaincha-N is added after a single crop of Dhaincha in a ha of land.
- It can also be grown as a intercrop or relayed with cereals.

Method of Dhaincha Farming (ढैचाको खेती गर्ने तरिका)

Dhaincha seeds are seeded in plowed land @ 40 kg seeds/ha for green manuring purpose and 15 kg seeds/ha for seed production and grown as a rotational crop. It can also be cultivated in marginal lands. Two types of Dhaincha green manuring are in practice.

- In-situ green manuring: Dhaincha seeds are seeded in the plowed land. Dhaincha plants are then incorporated in 6-7 weeks of planting and light irrigation it given for well decomposition of the Dhaincha which works as a manure for rice. After incorporation, rice seedlings can be transplanted after 2-3 days.
- Ex-situ green-manuring: In this method, Dhaincha plants (stems, branches and leaves) are grown in one place and then transported to another area where the crop is to be planted and then incorporated into the soil. This method is little bit tedious but equally important. Dhaincha can also be used as compost where the land is unirrigated or lacks soil moisture. Dhaincha some time can be grown in rice bonds for seed production or ex-situ green manuring.

4. *Azolla* (एजोला)

Introduction (परिचय)

Azolla is small floating aquatic fern. *Azolla* species live in areas where there is plenty of water. They are found in lakes, streams, swamps and other small water bodies. They are also called water velvet, water fern, mosquito fern, duck weed and red *Azolla*. They are found all over the world where the temperature and sunshine are suitable for their growth. It has different species. Some species are tropical or subtropical and some grows better in temperate condition. Some species has long roots. The *Azolla* plant (sporophyte) is made up of horizontal to vertical main rhizome bearing individual roots or root bundles at branching points and leaves are bilobed (ventral and dorsal lobes) which are arranged alternatively. The aerial dorsal lobe of leaf is thick and chlorophyllous and it develops a cavity where *Anabaena azollae* (Cyanobacteria) are found. A colony of cyanobacteria is always present on the apical maristem, in the dorsal lobes. The cyanobacteria *Anabaena azollae* is the species which live in Symbiotic association with *Azolla*.

The most remarkable feature of *Anabaena azollae* is to fix atmospheric dinitrogen (N_2). *Azolla*-*Anabaena* symbiosis can fix 2-4 kg N/ha/day which is equivalent to 10-20 kg of ammonium sulphate. It can provide a potential source of natural nitrogen for flooded crops such as rice. So *Azolla* can be used as a green manure (biofertilizer) for rice.

Types of *Azolla* Species (एजोलाका जातहरू)

Azolla belongs to the order salviniales, family Azollaceae *axollae* withy genus *Azolla*. It is classified into 2 sections: (1) *Azolla* and (2) Rhizosperma *Azolla* species such as

Azolla filiculoides, *Azolla caroliniana*, *Azolla mexicana*, *Azolla microphylla* and *Azolla rubra* belong to the section *Azolla* where as *Azolla nilotica* and *Azolla pinnata* belongs to the Rhizosperma section. Further, *Azolla pinnata* has two varieties such as *Azolla pinnata* var. *imbricate* and *Azolla pinnata* var. *pinnata*. In Nepal, *Azolla pinnata* and *Azolla filiculoides* can be found wildy grown in natural water bodies and swampy lands.





***Azolla*-*Anabaena* Symbiosis**

All *Azolla* species have their symbiotic relationship with the *Anabaena* (Cynobacteria). The *Azolla* plant take the plant nutrients from the water and soil and makes available to the cynobacteria which live in the leaf cavity of dorsal lobe of *Azolla*. The *Anabaena* which fix atmospheric

nitrogen provides to *Azolla* plant. In favorable condition, *Azolla* multiplication rate is very high, it can double its weight in every 3-5 days. It has exponential growth rate. *Azolla* can produce 2-4 kg of N/ha/day. N fixation work is accomplished in aquatic environment and is considered as indestructible natural nitrogen factory when *Azolla* plants are incorporated in paddy fields, nitrogen after decomposition of the fern is mineralized and released to the rice crop and hence, serves as a green manure to the rice (IRRI, 1987).

***Azolla* Propagation Methods**

Azolla species are propagated sexually and asexually (vegetatively). In sexual propagation, *Azolla* produces sporocarps containing both megasporocarps (female organ) and microsporocarps (male organ). These sporocarps mature on the plant in a week or more depending upon the environmental conditions. Both sporocarps are disintegrated from the mother fern releasing spores and are fertilized in water. Microspores germinate and release antherozoides and fertilize with megaspore gametophyte. This can occur within 5 days after initial contact of mature gametophytes. *Anabaena* colony consisted in the fern is entrapped in the shoot apex and true leaves. When the root and leaf appeared from cotyledon, the seedlings starts floating to the water surface and a new *Azolla* plant (sporophyte) is ready to grow. Hence sporophytic reproduction is completed.

On the other hand, the main propagation of *Azolla* is the vegetative way by fragmentation of its branches. The abscission layer of *Azolla* branch is weakened when it is

matured and is fragmented and separated by giving rise of the new *Azolla* plant. *Azolla* has the potential of maintaining an exponential growth rate (EGR). *Azolla* growth rate is influenced by a number of factors. The dry weight of *Azolla* has been reported to be 4-8 to 7.7% and N content to be as high as 6.5% but in general in field condition the N content varies from 3.5 to 4%. The N content of *Azolla* and its growth rate is greatly influenced by environmental factors.

Nutrient Requirements of *Azolla* (एजोललाई चाहिने खाद्यतत्व)

All the species of *Azolla* require necessary major and minor plant nutrients (NPK and micronutrients) for their rapid growth if soil is poor of these nutrients and less fertile. Phosphorus (P) is the most common nutrient limiting the growth of *Azolla*. It is supplied to *Azolla* @ 25-30 kg/ha in 3-4 split doses not exceeding the dose of P given to the rice crop. No extra P is required by the rice crop. *Azolla* has the ability to absorb P by luxury consumption. If soil is low in N content, urea is broadcasted at low amount as a starter. Application of potassium is required for the growth of *Azolla* in light textured soils. Molybdenum and iron application also influence the growth of *Azolla* and N fixation because these elements are required components of the nitrogenase enzyme which take part in nitrogen fixation. Application of N in small quantities help improve the tolerance of *Azolla* to adverse environment, however, application of combined nitrogen (urea-N) in higher amounts is not good because it reduces N-fixation of *Azolla*. *Azolla* can thrive well at a temperature range of 20-30 °C (Air temperature).

Water Quality

Water pH, salinity and water turbulence are the other factors affecting *Azolla* growth. The pH for optimum growth of *Azolla* is 4.5-7 pH. Waves and turbulence are deleterious to *Azolla*. It can cause premature fragmentation and death of *Azolla*. Further, it can reduce plant size, growth rate and N-fixation.

***Azolla* Pests**

Azolla which is very attractive host due to its *Anabaena* symbiont, a number of insect pest attack the fern. In addition, a number of other plants and algae are indirect pests of *Azolla* which compete for the same space and nutrients. The major pests of *Azolla* are *Pyralis* sps. and *Nymphula* sps (Lepidoptera), *Azolla* moth, cryptoblabes, aphids and snails (mollusca). Phorate for the snail and parathion and carbofuran are the insecticides that can be used to control for a variety of *Azolla* pests.

Importance of *Azolla* (एजोलाको महत्व)

Azolla is considered as a natural nitrogen (N) factory because it can fix atmospheric dinitrogen (N₂) with the help of *Azolla anabaena*. It is used as a green manure in rice paddies and rice yields are increased. Evidences show that it can accumulate as high as 10.5 kg N/ha/day and 36.3 t/ha of biomass, and has a doubling time of 4.8 days. Other reports indicated that 2.7 kg N/ha/day could be produced by *Azolla* under field condition (Talley *et al.* 1977). The enzyme nitrogenase which occurs in Heterocyst cells of *Anabaena*, is capable of reducing N₂ (dinitrogen) to ammonia (NH₃) which is taken up by the *Azolla* and after

its incorporation this nitrogen is supplied to this growing rice plants. Lumpkin and Pluekentt (1982) reported that nutrient content of *Azolla* is as follows (dry wt. basis):

Nitrogen (%)	-	1.96-5.3
Phosphorus (%)	-	0.16-1.54
Potash (%)	-	0.31-5.97

Adhikary *et al.* (1996, 2003) reported that it contains 2.8-2.9% OM and 0.19-0.27% N in soil after *Azolla* incorporation. He further reported that *Azolla microphylla* can produce 2.1-3.79% N and as high as 59.2kg/ha of nitrogen from a single crop of *Azolla* which was fertilized with 37.5 kg P₂O₅ and splitted four times. In Nepal *Azolla pinnata* and *Azolla filiculoides* species are available, which have the potentiality of producing as high as 30.1 kg N and 39.1 kg N with a single crop of *Azolla*, respectively. FAO (1988) reported that an extensive survey on *Azolla* was conducted in Nepal in 1982 and stated that *Azolla pinnata* was found widely occurring in all the mid hills and terai of Nepal. Experimental results indicated that *Azolla* application increased the rice yield by 25%, equivalent to 30 kg urea N/ha. Rice yield were found increased by 40% over control when the *Azolla* was incorporated twice during the rice growing period. Several experiments with *Azolla* in rice were conducted by Soil Science Division, NARC, Khumaltar during the years 1990/91-1993/94 and reported that application of *Azolla* increased the rice yields. From the results it was observed that 57 kg of urea-N combined with 10 t/ha of *Azolla* (30 kg N from *Azolla*) produced the similar yield to that obtained from 87 kg of urea-N

(Anonymous, 1993). Split application of P on *Azolla* greatly determine the nutrient content of *Azolla microphylla* (Adhikary *et al.* 1997).

Effect of P topdressing on *Azolla*

	Fat %	Crude fibre %	Ash %	N%	Protein %
Basal P (P ₁)	0.77	18.4	19.0	1.73	10.8
Two splits of P (P ₂)	1.41	18.7	26.0	2.99	18.6
four splits of P (P ₄)	1.38	16.9	21.0	3.06	19.1

Azolla is very useful to rice because it can supplement N and hence we can use less amount of urea-N to the rice paddies. It is not only useful to rice but also it can be used for different purposes such as:

- Fodder and silage for livestock and poultry
- Forage for fish
- Green manure for crops other than rice
- Use of *Azolla* in making of compost
- Weed suppression
- Ornamental: Some *Azolla* species are used as ornamental plants in ponds or aquatic gardens. *Azolla caroliniana* is one of the suitable species for ornamentals because it produces brilliant crimson pigments under stress condition. Some species produces anthocyanin pigments which looks red in color while floating in the pools and ponds.
- Mosquito control because of its development of thick mat. Mats are thought to prevent laying eggs and prevent larvae to come up for the air.
- *Azolla* for human consumption: A number of evidences prove that it can be used as food for human beings. *Azolla*

contains high level of proteins and is very nutritious, tasty and donot cause any difficulties in digestion, (Lumpkin and Plueknett, 1982).

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