Volume II. Chapter 1
Selection of crops, crop associations and crop successions adapted to agro-climatic constraints

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1. Objectives

In order to put in place a suitable advisory system, in an integrated approach at the terroir level, it is necessary to master a range of cropping systems adapted to local conditions. This requires identifying the nature of the most appropriate crops and the order of their succession and/or association, as well as the operational sequence to be applied to these crops or crop associations.

This range of cropping systems should allow the proposal of systems adapted to different farm situations, and for this purpose it should:

• cover the main soil x water regimes encountered in the area;
• be sufficiently diversified in order to offer a wide choice in terms of main crops within the systems, level of intensification, necessary resources, risk taking, integration with livestock, etc. This wide range developed at zone level subsequently allows selecting, at the plot level, the most suitable systems to local terroir conditions, and to farm characteristics;
• not be too vast, in order to be «manageable» and easily understood by managers, technicians and farmers. That is why systems are based primarily on the main crops of the area, and offer diversified solutions to local major agronomic and socio-economic constraints.

Thus, this range of systems to be developed depends on the major constraints of an intervention zone and is chosen according to the different types of environment encountered. An initial diagnosis, and in particular the definition of «agronomic units», is therefore essential to integrate these parameters in the design of the system.

2. Identification of agronomic units

In order to design (and present to farmers) DMC systems adapted to local conditions (right down to plot level) based on readily identifiable criteria, it is essential to distinguish the different agronomic units encountered at zone level and to recognize them rapidly on the field.

These units are defined by the homogeneity of their agronomic characteristics: toposequence position, soil fertility and level of compaction, and water regime. The agronomic potential and constraints within an agronomic unit largely explain the existing systems; and determine the DMC systems that are possible to propose. It is therefore essential to define the agronomic units to take into account the criteria that will make a DMC system possible or not.

A first fundamental distinction to make is the one between:

• tanety (and low slope colluvial soils); and
• plains, valleys or lowlands.

The water regime is fundamentally different and therefore has a strong impact on the possible systems (possibility of installing crops during the off-season).

2.1. Discriminating criteria in tanety

In tanety we can distinguish (if applicable) tanety with pure rainfed crops from those developed in terraces (which may be irrigated or not, and more or less controlled).

The main criteria to consider are soil compaction and its initial fertility, which determine the possible crops
and the level of required inputs. Soil fertility and the level of compaction can be estimated locally based on natural flora and crop development.

Then we can focus on the possibilities of off-season cropping. By this we mean the possibility of obtaining a high biomass production outside the main growing season. This does not necessarily mean growing a second crop, but the possibility of installing a cover plant that can be established within the crop, in order to obtain a proper establishment of the main crop before the arrival of the dry and/or cold season.

In tanety, these possibilities are very unlikely in environments with long dry season (South West, Mid-East and Lake Alaotra). There are more possibilities in the highlands (on non-compacted soils) and especially in a humid tropical climate, all year long (South East).

Finally, if applicable, we must concentrate on a very strong specific agronomic constraint (often the most limiting one), such as the pressure of Striga on cereals in the Mid-West of Madagascar.

### 2.2. Discriminating criteria in the plains, valleys and lowlands

In those environments where soil fertility level is moderately high or high, fertility is not very discriminatory. The main factor to be considered is the water regime, along with the three following parameters:

- risk of waterlogging, which determines if we can grow another crop instead of rice during the rainy season. So we distinguish between exposed or drainable soils, on which waterlogging is rare or very temporary and where we can grow a crop such as maize, and soils flooded for more than five consecutive days, with no possible drainage, where only rice can be grown during the rainy season;

- access to irrigation. Here we consider access to irrigation during the main season (and not necessarily during the off-season) which allows us to secure a rice crop. So, we distinguish between plots without irrigation; those with random irrigation (rice fields with poor water control, in which water can be provided at a moment of the cycle, but in an undetermined way) and those with controlled irrigation, in which we can provide water when desired during the rainy season;

- possibility of off-season cropping. Once again, off-season means the ability to produce a high amount of biomass outside the main cropping season. On one hand, these possibilities are linked to climate, but also to:
  - soil type: soils with a high clay content, or on the contrary, the presence of a sandy horizon (which creates a capillary break) and prevents the capillary rise of water;
  - toposequence position: groundwater depth during the dry season, possibility of drainage when the cover plant should be established, etc.;
  - possibility of irrigation during the off-season (rare in Madagascar).

These different criteria allow us to discriminate agronomic units for which we can then design a range of differentiated DMC systems.

A final factor regarding the water regime is the period during which a rice field can be flooded, which determines the possibility of doing rice monoculture (we can estimate that with more than 45 days/year of waterlogging, rice monoculture is possible each year without off-season cropping).
3. Rapid initial diagnosis

The design and implementation of demonstrations on DMC systems locally adapted at the terroir level presupposes a sufficient knowledge of the environment and of farm practices in the particular terroirs. An initial diagnosis (cf. Volume VI: «terroir approach») is therefore essential before any intervention. This rapid diagnosis should permit us:

- to locate ourselves easily in the landscape, by identifying the main agronomic units present at the terroir level;
- to be aware of farm practices at the terroir level, according to the different landscape/agronomic units. This is essential in order to propose to the farmers systems that are built primarily from their own systems, with their preferred crops;
- to identify the main factors that limit agricultural production in different situations;
- to identify farmers’ needs and constraints as well as the existing opportunities to improve systems and/or to use abandoned land;
- to understand the interaction between agriculture, livestock and off-farm activities, in particular sharing manpower and means of production (inputs, equipment) between the different activities, at the level of landscape units, and the priority given to each by farmers in case of shortage.

Performed at the level of an intervention area, this diagnosis allows us to take into account the environmental conditions and the main constraints (agronomic and socio-economic) in order to develop a wide range of systems able to eliminate the major constraints, to sustainably improve production, and to be easily integrated at the farm and terroir level.

By sharpening this diagnosis at a terroir level, we can then «build» systems most adapted to local conditions and choose a small number of systems that can be eventually displayed at the terroir level.

In order to advise farmers, the diagnosis must be done at this scale. This allows the choice of some systems well adapted to each farmer based on technically feasible and interesting systems at the terroir level.

4. Identification of possible systems in a given situation

For a given plot and thus, for a given agronomic unit (agro-ecological zone, landscape unit, soil type, water regime), technically possible systems depend on a certain number of agronomic factors. It is essential to identify and characterize them during the rapid diagnosis before any intervention.

4.1. Factors to be taken into account

For the identification of possible crops and cover plants in year «zero» of direct seeding preparation, eight main factors must be taken into account:
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

**Climate**

Climate is the first factor to be considered when identifying potential crops (those that farmers have naturally grown) and cover plants that can be used. This factor, is difficult to control (only by irrigation or greenhouse cultivation, all very expensive), strongly influences the choice of species and varieties, as well as the timing of crop cycles and the possibilities of crop association or succession. The two main criteria are obviously precipitation (total amount, distribution, occurrence of a dry season, etc.) and temperature (particularly cold periods and risk of frost) which strongly influence biomass production.

**Examples of climate influence**

In the Malagasy highlands, relatively low temperatures extend the crop cycle, and we cannot cultivate plants which demand high temperatures (which fail to complete their cycle before the arrival of the cold season). Thus, dolichos bean and *Vigna umbellata* grow very poorly at altitude and only short-cycle cowpea varieties (like “David”) can be cultivated, as long as they are sown early.

In the semi-arid south-western part of Madagascar, the short rainy season makes that maize cultivation can only be done with short-cycle varieties (such as CIRAD 412), established since the first rains.

**Irrigation**

In contrast, irrigation allows the grow of some crops and provides flexibility for crop cycle timing.

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**Examples of hydromorphy**

Most plants, and especially legumes, resent hydromorphy or waterlogging, and even less submersion. Among grain legumes, cowpea is the one that copes better with excessive water. For ground cover, the legumes *Sesbania* and *Aeschynomene* are very well adapted to hydromorphy. Stylosanthes guianensis species tolerates it well and even submersion (except the very young plants). Among cereals, rice is very tolerant to excessive water, unlike maize, oats or wheat. *Brachiaria humidicola* and *B. mutica* are forage grasses very well adapted to hydromorphic environments.

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**Le régime hydrique : hydromorphie, engorgement, submersion et possibilités de contre-saison**

Hydromorphy and waterlogging and/or submersion risks

As hydromorphy and waterlogging are poorly tolerated by many cultivated crops (particularly legumes), it is important to identify the risk level of a plot, especially in low lying positions and humid climates. The risk of waterlogging or submersion in given periods will determine which crops can be cultivated (species and varieties), but also the cropping period (and thus crop cycle timing) and the operational sequence (such as building a drain). When there is a risk of submersion that exceeds five consecutive days without any possible drainage, only rice can be grown during the rainy season.

**Operational sequence:**

Crop cycle timing
Drainage
Seeding pre-germinated seeds
Rice transplanting

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**Possible crops :**

Species
Variety
Crop association and succession
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

Groundwater and off-season possibilities

Examples of off-season cropping

In the baiboho (alluvial deposits) of Lake Alaotra, the groundwater descends slowly during the dry season, and remains close enough to the root system of plants cultivated in the off-season, which allows them to reach water easily. Off-season crops are relatively easy to grow. However, there are some baiboho with sand lenses that disrupt capillary rise and do not permit, or make it very difficult, to support an off-season crop.

In upland rice fields, the groundwater is generally shallow and allows off-season cropping. However, the establishment of a plant such as vetch, which does not stand waterlogging and must be seeded early enough to establish itself before the arrival of cold days, can be problematic in undrainable plots.

The possibility of rapid access by the roots to groundwater largely determines the possibility of off-season cropping. Groundwater depth and its rate of descent allow or not, root system connection with the groundwater and thus plant growth during the dry season. All plants do not have the same ability to follow the groundwater in its descent and to grow during the off-season. Plants, such as dolichos bean or sorghum, have a root system able to develop rapidly (sorghum roots can grow up to 3 cm per day), to follow the groundwater descent, and which may descend deeply (up to 3 m). They enable a high biomass production by using «residual» water, and are therefore excellent cover plants for DMC in environments with a long dry season.

On the contrary, in lowland areas, plants can suffer from an excess of water at the end of the rainy season, when the off-season crops should be grown. This leads to a shorter biomass production period (which decreases the performance of systems) and can make the implementation of certain systems very difficult, especially in altitude where the cold season slows plant growth, and where frost can kill young plants that still have low resistance.

Factors to be taken into account

Possible crops in off-season:
Species
Variety
Crop association and succession

Operational sequence:
Crop cycle timing
Drainage
Irrigation

Examples of off-season cropping

<table>
<thead>
<tr>
<th>Groundwater depth and rate of descent</th>
<th>Possible crops in off-season</th>
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<tr>
<td>Capillary rise</td>
<td>Species</td>
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<td></td>
<td>Variety</td>
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<td></td>
<td>Crop association and succession</td>
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</tbody>
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Oats on tanety in off-season
Highlands

Dolichos bean connected to the groundwater in the plains. Lake Alaotra
Highlands

Off-season vetch in rice field
Highlands
Deep soil compaction and sealing

The state of compaction or induration of soil has consequences on possible crops, with two major limiting situations:

Existence of a tillage pan or deep soil compaction

Before any intervention, it is essential to ensure that there are no deep compacted horizons. In particular, on plots tilled regularly, a tillage pan frequently develops at 10-20 cm, caused by repeated tillage at the same depth. This horizon, as it is a barrier to deep rooting, must be identified especially in upland crops on *tanety*, for which rooting depth determines useful water reserve in the soil.

In the case of tillage pan or deep compacted horizons, which cannot be eliminated by tillage (or that could be removed by sub-soiling, but at a prohibitive cost inaccessible in Madagascar), only plants with a strong root system, or when shallow rooting is sufficient for their development, can be proposed to farmers. Crops like upland rice, which require a high degree of soil macroporosity and have a strong root system, should be established only after the restructuring of the compacted horizon.

Therefore, the evaluation of the degree of soil compaction is a fundamental step in the crop selection process.

Examples of compaction

Upland rice is a crop that needs a well-structured soil. It must not be grown in compacted soils. Maize and sorghum have a stronger root system, which allows them to grow on relatively compacted soils.

The pinto peanut or bambara groundnut has a less powerful root system, but shallow rooting is sufficient for its development.

Grasses (such as brachiaria) are real «machines» for soil decompression thanks to their very powerful root system and their ability to revive biological activity. This decompression capability increases even more when legumes with powerful pivot roots such as *Crotalaria* and *Cajanus* are associated with brachiaria grasses.

Soil compaction

The degree of soil compaction strongly influences possible crops and systems when we want to grow them under DMC. It is therefore essential to evaluate it before any intervention, with simple indicators that are available, such as the natural flora. *Urena lobata*, *Cassia tora*, or scattered *Aristida*, are indicative of a high risk that the soil is compacted, while conversely well-developed *Cynodon dactylon* or *Hyparrhenia sp.*, are indicators of good porosity.

However, it is highly recommended to do soil profiles because it provides interesting information on the degree of compaction and on the rate of descent of the root system (whether natural vegetation or cultivated plants).

Soil profiles allow evaluating soil compaction by the sound produced by the different horizons when tapped (for example with a knife handle): the more acute the sound is, the more compacted is the horizon. So, tapping different horizons and listening to the sound variation allow being aware of the degree of relative compaction of the different horizons, and to identify compacted layers.

The difficulty of digging a profile at certain horizon level also provides information on compaction degree. However, when evaluating soil compaction, the humidity of the soil profile must be taken into account (soil gets harder as it dries).
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

Sealed soils or indurated at the surface

Sealing phenomena (formation of a thin «sealing» crust, linked to rain action on soils with very fine particles, but not colloidal) or soil surface induration (caking of the first centimetres of a very unstructured soil, often after heavy rains) also has an impact on possible crops, but to a lesser extent than deep compaction. Some crops tolerate the asphyxiating conditions created by a crust on the surface very badly. These phenomena have a stronger influence on the operational sequence during year «zero» (sealing being eliminated by direct seeding mulch), particularly in terms of soil tillage and mulch requirements.

Example of sealing

*Vigna umbellata* does not tolerate sealing phenomena and should not be grown in sealed (such as ferruginous tropical soils) bare soils (without plant cover).

Deep soil compaction

Sealing
Surface induration

Possible crops:
- Tolerant species
- Species that allow restructuring the soil rapidly

Operational sequence:
- Tillage
- Plant cover

The initial level of soil fertility and possibilities to improve it and to correct nutrient deficiencies

The initial level of soil fertility has an impact on possible crops and on their production level, as well as on fertilization levels (depending on the crop) and weed management requirements.

Before any intervention, it is essential to estimate the level of soil fertility, which can be done very simply by observing:
- the natural flora: for example, plants like Aristida sp., Heteropogon sp., Chrysopogon or Imperata cylindrica are indicative of degraded soils and of low or very low fertility when these plants are poorly developed and dispersed. *Striga* is linked to a serious degradation of soil organic status. On the contrary, Hypparhenia sp., Stenotaphrum sp., Eleusine indica, Cynodon sp. (well developed) and many broadleaf weeds such as Acanthospermum hispulm, Galingosga parviflora or Tridax procumbens are indicative of relatively fertile soils. The presence in abundance of the weed Conyza sp., Age-ratum sp., etc. is also indicative of good soil fertility;
- the type of crops grown by farmers and their development (without fertilizers): a well-developed maize crop indicates good fertility. Rice also (but it supports better acidity than maize), and to a lesser degree, soybean. If their development is fairly low (production around 500-800 kg/ha), the soil has medium fertility. The absence of these crops suggests low fertility, especially when only cassava, pinto peanut or bambara groundnut are possible according to farmer statements;
- the crop condition, particularly demanding crops such as rice or maize. We must pay special attention to symptoms of deficiency in major element (N, P, K, S) but also of trace element (B, Zn, Cu, Mn, etc.) deficiencies.

The possibilities of correcting soil nutrient deficiencies, improving soil fertility (application of manure and/or fertilizers, soil smouldering, etc.) and correcting acidity (amendments) allow the growth or not of demanding/susceptible crops. They are a major factor for

Maize crop on very poor soil after fertility rising by soil smouldering practices
Highlands
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

Increasing biomass production during the early years, before soil fertility level had been improved by direct seeding mulch-based practices.

Examples of soil fertility

On a low fertility soil, demanding crops like maize cannot be grown without fertilizer (mineral or organic). If fertilization is expensive, its profitability may be low (or even negative), especially on very poor soils where a demanding crop is not profitable. In such cases, it is better to grow less demanding plants (bukuyu groundnut, cassava, beans, etc.), which will better valorized an eventual fertilization than demanding crops.

On rich soils, fertility benefits crops, but also weeds. So, the operational sequence must be adapted to ensure good weed control.

On medium-fertile soils, maize fertilization is often interesting because it will significantly increase yields as well as biomass amount (its residues will feed direct seeded crops in the following season). However, if the interest owed to borrow the amount needed to purchase fertilizers is high, and/or if the risks of failure are high and difficult to bear, the use of mineral fertilizers is not interesting. Then, it is better to grow an undemanding crop.

The use of mineral fertilizers (expensive) supposes that financial resources are available (as long as all the benefits obtained from fertilizer input won’t be lost), that the necessary inputs are accessible and that farmers are able to bear the risk that such an investment represents. Risk should be clearly identified and assessed. It also supposes that one is sure that benefits will result from the effect of fertilizers (good weed control, low climate risk, etc.).

If it is not possible to use fertilization (mineral or organic), then growing cover plants (especially legumes) can be a good alternative if they can be kept in place for a sufficient long time.

Examples of weeds

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Factors to be taken into account

Mobilisable capital and/or labour

Initial level of soil fertility

Possible crops:
- Species
- Variety
- Crop association and succession

Accessible inputs

Possibilities to improve soil fertility

Operational sequence:
- Fertilization
- Crop cycle timing
- Seeding rate and spacing
- Weed control

Example of weeds

On baibo (rich soils), where weed pressure is high, rice cultivation is only of interest if means of weed control are available (herbicides or an abundant work force). If means of weed control are limited, it is more interesting to grow maize, in which it is easier to control weeds and as maize is less sensitive to weed competition than rice. When associating maize with a legume that rapidly covers the soil, weed pressure is greatly reduced and it is possible to grow rice during the following year.
Some systems are particularly useful for controlling specific weeds such as Striga (cf. Volume I, Chapter 3). It is important to identify particularly noxious weeds during diagnosis and to propose systems that control them.

Cyperus rotundus, weed difficult to control

Examples of bio-aggressors

At Lake Alaotra, the plots on the edge of the plains are under great pressure due to Heteronychus sp. and the presence of white grub, that leak from rice flooding. The pressure is so high that it is difficult to control them, even with the use of chemical substances. Thus, it is better to implement legumes during this period, which are less sensitive than cereals. It can also be used around the cropping plots, repellent covers (aromatic plants: vetch, radish, desmodium) and/or plant covers which, on the contrary, are very attractive and serve as traps and divert insects away from crops (Pennisetum sp. for borers, and Arachis for bugs. Anglo-Saxon «Push-pull» system).

Bio-aggressor pressure and available control resources

Bio-aggressor pressure also depends on many factors: climate, presence or absence of auxiliary insects that control pests, toposequence position (water regime), soil fertility level and fertilizer inputs (type of nitrogen supply, especially for fungal diseases), resistant or sensitive varieties, previous crops and operational sequence, etc. Consequently, the pressure of bio-aggressors varies greatly according to the situation. It must be identified during the preliminary diagnosis, in order to ensure that crops sensitive to local pests will not be proposed in the early years (choice of species and varieties) if there are no efficient and low toxic treatments (insecticides, fungicides).
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

The risk of straying animals and/or fires and ways to conserve biomass
The biomass produced and returned to the soil is a key factor in the effectiveness of DMC systems, so it is essential to ensure that it can be maintained on the plot in sufficient quantity. In case of a high risk of straying animals and/or fire that would be impossible to control at the terroir level (by stopping common grazing, hedging, etc.), only systems producing a very high amount of biomass (including roots) and especially systems using non-palatable and/or fire resistant cover plants (remaining green during the dry season, restarting rapidly after eventual fire) can be proposed. In the highlands, in areas where dairy farming is one of the main sources of income for farmers and where the demand for fodder is very important, the proposed systems should enable high biomass production, in particular root biomass. «Dressing» crops with temperate cover plants (and/or fodder), such as oats, is one possibility as long as you ensure maintaining sufficient biomass in the soil (a condition for DMC success). It is also possible to propose systems based on biomass production using perennial plants for forage production (taking care of fertility management by returning exported minerals to the soil), pastures that are regenerated after a few years, by growing them under DMC systems associated with a crop (which pays the cost of regeneration).
Finally, in some environments with high population density, where trees have almost disappeared, crop residues are sometimes used as fuel. Thus, it is essential to work on terroir management and re-afforestation activities.

Possible crops:
- Interesting species
- Crop association and succession

Fire risk
Importance of livestock
Terroir management:
- Common grazing,
- collective grazing lands

Pressure on biomass

Operational sequence:
- Crop cycle timing
- Hedging
- Firewalls

Risks and security level
For every investment, there is a risk. The level of security of the return on investment plays a key role in the decision process. The systems and operational sequences are often adapted by farmers in order to minimize these risks. DMC systems allow reducing certain risks (drought, fire, insects, etc.) but cannot secure all production factors and especially “no-agronomic” risks (robbery, etc.).

Examples of risks
A farmer who is not sure of keeping his plot (land insecurity) is generally reluctant to invest in the improvement of cropping condition. He often prefers low-intensive systems and with a very rapid economic return. Tenant farming («renting» land at a fixed price) increases the farmer’s risk in case of failure, and his profits in case of good production. Inversely, share-cropping (sharing harvest) reduces losses of the share-cropper in case of poor production, but also his gains if it succeeds, which greatly limits its interest to conduct intensive crops, risky.
Thus, the absence of land tenure security is a handicap for the development of systems that do not allow a rapid return (investment in soil fertility, for example). The high risks of losing production of standing crops (frequent in the highlands) and robbery (common throughout the Island), severely limit the interest of the farmer to invest in crop intensification. The DMC systems proposed in these high-risk situations are consequently low-intensive systems.

Summary of key factors that determine the cropping systems that are technically possible

Cropping systems and operational sequences that are technically feasible are based on specific parameters: at the terroir: climate (directly, but also indirectly through its influence on plot characteristics) and pressure on land and biomass;

- at the farm: possibilities to increase soil fertility and weed control methods;
- at the plot: initial fertility level of soil, compaction and sealing, hydromorphy and waterlogging risk, weed pressure, etc.

Cropping systems and operational sequences are linked: operational sequences are determined according to the system and to the specific conditions (plot characteristics, available resources). Some systems, under certain conditions, are only possible if a specific operational sequence is carried out (for example, application of fertilizer on poor soils when growing a demanding crop).
4.2. Identification of crops, crop associations and successions possible to initiate rapidly direct seeding mulch-based cropping systems

Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

From an agronomic point of view, entering into direct seeding (which consists of «priming the pump» by obtaining high biomass production) can be more or less rapid, according to initial conditions and available resources. A compromise must be sought to find systems that meet the needs, while maximizing production and incomes with the available resources and taking minimal risks.

**Stage 1. Identification of crops possible in year “zero”**

For the first year(s), until that the improvements obtained by DMC systems are felt, cropping systems must allow the establishment of cover plants (which will help to overcome the main constraints), as well as crop production (sole cropping cover plants is expensive and immobilizes the plot without providing income). From a practical point of view, when selecting the cropping systems and the respective operational sequence, the first thing to do is to take cognizance of the degree of deep soil compaction and sealing of the plots concerned, waterlogging risk, initial fertility and resources available to increase soil fertility.

Based on the summary table (Table 1. Adaptation of the main crops grown under DMC in Madagascar. Page 14), it is possible to establish (by elimination) a list of crops that are possible to grow under the described or particular conditions (soil, climate), with the available resources. Firstly, we eliminate the plants that are not adapted to the climate and those sensitive to compaction (if the soil is compacted), to sealing (if any), and to waterlogging/hydromorphy (on risky plots). Finally, among the remaining plants, we can identify the crops that are possible to grow and the necessary resources (fertilizer input, weed control, etc.):

- on compacted soils, we grow crops tolerant to compaction (strong root system such as sorghum or plants which can grow with a shallow root system, such as bambara groundnut);
- on poor soils, we use undemanding plants (cassava, etc.) or fertilization (fertilizers, slash-and-burn practices) if more demanding plants (making sure of being grown under the conditions that allow the good use of added fertilizers: limited climatic risks, weed control, etc.);
- under heavy weed pressure we use crops that are easy to weed or insensitive to weed pressure, or we ensure good control by weeding, hand-pulling and/or using herbicide;
- under heavy insect pressure, we grow insensitive crops (resistant species or varieties) or use treatment (insecticide on seeds or on plants), as well as in case of eventual diseases.

Similarly, we identify the cover plants that can be used in these environments, with the available resources (Table 2. Adaptation of the main cover plants used in DMC systems in Madagascar. Page 15).
Establishment of direct seeding cropping systems  
Selection of crops, crop associations and crop successions

<table>
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<tr>
<th>Adaptation to</th>
<th>Rice</th>
<th>Maize</th>
<th>Sorghum, Millet</th>
<th>Wheat, Barley</th>
<th>Soybean</th>
<th>peanut</th>
<th>Bean</th>
<th>Ground pea</th>
<th>Cowpea</th>
<th>Vigna umbellata</th>
<th>Dolichos bean</th>
<th>Vegetable crops</th>
<th>Potato</th>
<th>Cassava</th>
<th>Sweet potato</th>
<th>Cotton plant</th>
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<tbody>
<tr>
<td>sub tropical highland climate, with frost (Altitude &gt; 1,500 m)</td>
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○● : Very good  ● : Good  Empty : Medium  - : Bad
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

Table 2 Adaptation of the main cover plants used in DMC systems in Madagascar Climate and plot characteristics

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<th>Mucuna</th>
<th>Vetch</th>
<th>Stylosanthes</th>
<th>Pinto peanut</th>
<th>Desmodium</th>
<th>Clover</th>
<th>Cajanus</th>
<th>Crotophorus</th>
<th>Oat</th>
<th>Eleusine</th>
<th>Ryegrass</th>
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- : Very good  • : Good  Empty : Medium  - : Bad
Stage 2. Identification of the most interesting plants to remove the main agronomic constraints rapidly

As a priority we seek to include in these cropping systems, plants with interesting and complementary agronomic and environmental functions, in order to overcome the major agronomic constraints and to move over to DMC as soon as possible. These agronomic functions (soil restructuring and enrichment, weed control, etc.) are nevertheless satisfied sooner or later (and more or less effectively) depending on the plants, the cropping systems and the operational sequence used. Table 3 (page 18), pulls together the agricultural interests in the cultivated plants and Table 4 (page 19), presents the agronomic interest of cover plants used in DMC in Madagascar, allowing the selection of plants able to produce a high biomass rapidly and to overcome the main agronomic constraints (compaction, fertility, weed, etc.):

• on compacted soils, we use cover plants with a very strong root system and which enable the development of significant biological activity, particularly grasses (brachiaria, for example), and some legumes such as stylosanthes;
• soil enrichment can be achieved by the use of plants able to recycle nutrients (potassium, bases, etc.) and/or plants able to fix large quantities of nitrogen, in association and/or in succession with undemanding or fertilized crops;
• weed control is done by producing a high biomass that is maintained on the soil, and/or by using plants with allelopathic effects;
• control of some insects can be done through the use of plants with insecticidal or repellent characteristics (fodder radish, for example).

Thus, we get a list of the possible species to be cultivated and the most interesting plants to overcome the major agronomic constraints rapidly.

Stage 3. Identification of crop associations and successions technically feasible and interesting to overcome the main agronomic constraints and to obtain high biomass production rapidly

The last stage is to determine the cropping systems that optimize the use of different species, in order to ensure sustainable agricultural production and to overcome the main constraints. As much as possible, besides crop succession when they are possible, we use association of cover plants with crops less sensitive to existing agronomic constraints (that we are trying to overcome) that allow obtaining rapid revenues. We also try to intercrop plants, use of which is as easy as possible, in order to be compatible with the available resources. Finally, whenever possible, we use plants that produce consumable grains and/or that can be partially used as fodder to feed animals. Eventually, these plants can be used in mixtures (while being careful to create mixtures of plants that can be easily controlled before the next crop) to fulfil a range of complementary agronomic functions.

High cropping intensity on rich volcanic soils in the highlands
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

Factors to be taken into account
The parameters to consider when choosing crop associations/successions are:

• the length of the growing season, itself a function of:
  - climate, which determines the availability of water and the temperature, the possible growth period for different plants and;
  - toposequence position, and the water regime that determine the possibilities of access to water and therefore production possibilities outside the rainy season (and conversely, flooding risk during the rainy season);
• land use intensity (number of crop cycles per year), linked to population density and/or soil initial fertility, and fodder requirements to feed animals.

These factors are difficult to control/modify and directly affect the possibilities of crop association or succession.

Other factors also play an important role in the possibilities of crop association and succession:

• characteristics of the chosen varieties of crops and cover plants: cycle, vigour at the start and habit (which determine the risk of competition for light), eventual photoperiodism, tolerance to cold and drought (which determine the potential production periods), root system performance and growth rate (which influence the risk of competition for water and nutrients);
• soil fertility level (including the risk of micronutrient deficiencies) that influences the respective growth rate of different plants (and thus the competition for light), and which can moderate the impact of competition for nutrients. Fertilization can facilitate system management and increase biomass production.

However, these factors are less decisive because it is possible to moderate their effects by choosing an appropriate operational sequence (choice of varieties with more favourable characteristics for these conditions, localized fertilization, delaying seeding, adjustment of the distance between plants, etc. cf. Volume II. Chapter 2.).

Thus, crop association/succession possibilities are directly related to the agro-ecological zones. Some are possible in many situations but more or less easy to implement, others are only possible under certain soil and climatic conditions (cf. Volume I. Chapter 1. and Volume I. Chapter 2.).
### Table 3. Agronomic interest of main crops grown under DMC in Madagascar

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<tr>
<th>Soil decompaction and organic matter content increase</th>
<th>Rice</th>
<th>Maize</th>
<th>Sorghum, Millet</th>
<th>Wheat, Barley</th>
<th>Soybean</th>
<th>peanut</th>
<th>Bean</th>
<th>Bambara groundnut</th>
<th>Cowpea</th>
<th>Vigna umbellata</th>
<th>Dolichos bean</th>
<th>Vegetable crops</th>
<th>Potato</th>
<th>Cassava</th>
<th>Sweet potato</th>
<th>Cotton plant</th>
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#### Key
- •••: Very good
- •: Good
- Empty: Medium
- -: Bad
Selection of crops, crop associations and crop successions

Mucuna  Vetch  Stylosanthes  Pinto peanut  Desmodium  Clover  Cajanus  Crotalaria  Oat  Eleusine  Ryegrass  Brachiaria  Kikuyu grass  Fodder radish  Lupin

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>Mucuna</th>
<th>Vetch</th>
<th>Stylosanthes</th>
<th>Pinto peanut</th>
<th>Desmodium</th>
<th>Clover</th>
<th>Cajanus</th>
<th>Crotalaria</th>
<th>Oat</th>
<th>Eleusine</th>
<th>Ryegrass</th>
<th>Brachiaria</th>
<th>Kikuyu grass</th>
<th>Fodder radish</th>
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</table>

**Key:**

- **•••**: Very good
- **•**: Good
- **Empty**: Medium
- **-**: Bad
The synthesis tables (table 5 - 9) present crop associations and successions possible in the different agro-ecological zones.

**Crop associations and successions in medium-altitude climate (600 to 1,100m) with long dry season (Lake Alaotra, Mid-Eastern region)**

In this type of climate, several crops and cover plants can be used. The pronounced dry season makes impossible the intra-annual succession of crops on tanety, where only crop associations and inter-annual successions are possible. On the other hand, in lowland areas (bai-boho, rice fields), the plants that root fast and are able to connect with the groundwater (dolichos bean, vetch, etc.) can be grown in succession with the major crops.

In all situations, perennial plants (stylosanthes, brachiaria) grown with the main crop can be used to produce biomass during the dry season (for several months without rain on tanety, throughout the dry season in lowland areas).

In rice fields with poor water management and on bai-boho that allow off-season cropping, rice/vetch succession is particularly interesting (weed control and high nitrogen fixation capacity of vetch).

**Example of selection in Lake Alaotra**

On medium-rich and not compacted tanety in the East shore of Lake Alaotra and on rich bai-boho, farmers grow rice and preferably maize. A major constraint is the high weed pressure. Therefore, it is preferable to start the cropping system with maize, which may be associated with a plant cover (legume) that will enrich the soil and help to control weeds by producing high amounts of biomass. If land pressure is high (in the case of bai-boho), a twining legume (dolichos bean, cowpea, Vigna umbellata) has the advantage of producing grains and allowing rice cultivation in crop residues, the following year. If available space allows it, it may be better to intercrop maize with stylosanthes, which will be left in place during two years in order to enable rice cultivation under excellent conditions (total weed control, soil enrichment), in the following year.

---

### Table 5. Possibilities of crop association and intra-annual succession of the main crops grown in medium altitude (Lake Alaotra and Mid-Eastern region)

<table>
<thead>
<tr>
<th>Soybean, bean</th>
<th>Peanut/bambara groundnut</th>
<th>Dolichos bean</th>
<th>Vigna umbellata</th>
<th>Cowpea</th>
<th>Mucuna</th>
<th>Vetch</th>
<th>Stylosanthes</th>
<th>Perennial peanut</th>
<th>Crotalaria, cajan</th>
<th>Brachiaria</th>
<th>Eleusine</th>
<th>Oat</th>
<th>Vegetable crops, potato</th>
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<tbody>
<tr>
<td>Rice</td>
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<tr>
<td>Maize, sorghum</td>
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</table>

++ Very interesting crop association and easy to manage
+ Rather interesting crop association, but demands a specific crop management
☐ Interesting crop succession cropping (only possible in lowland areas)
Empty: Crop association or succession with little interest and/or difficult to manage
— Crop association or succession very difficult to manage or impossible (incompatible plants)
Crop association and succession in subtropical highland climate (highlands), frost-free zones (1,200 to 1,500m)

In the highlands of Madagascar, the main constraint on the establishment of crop successions is the pronounced cold season, which limits the possibilities of biomass production, even when water is not a limiting factor. Consequently, only «temperate» plants (oats, wheat, barley, ryegrass, vetch, etc.) allow growing successions and producing high biomass during the cold season. Crop association with perennial cover plants (stylosanthes, brachiaria, etc.) is also possible, but biomass production during the cold season is very limited. However, these plants allow significant biomass production in late hot season (after the main crop harvest) and from the end of the cold period, before crop establishment.

Growing perennial plants by using direct seeding over a living cover crop is also an interesting option. Thus, we can grow legumes on a living cover of grasses (Kikuyu grass) or, conversely, cereals (maize, rice) on a living cover of perennial legumes (perennial peanut, desmodium, clover, etc.).

When forage demand is very high (dairy farming areas), it is important to substantially increase biomass production and to export it in a rational way (soil fertility restoration, maintaining sufficient amount to ensure DMC’s efficiency, especially during the first years, in order to «initiate» DMC’s pump).

Table 6. Possibilities of crop association and intra-annual succession of the main crops grown in altitude, frost-free (highlands, 1,200 to 1,500m)

<table>
<thead>
<tr>
<th>Crop association</th>
<th>Soybean, bean</th>
<th>Peanut/bamba groundnut</th>
<th>Cowpea</th>
<th>Vetch</th>
<th>Stylosanthes</th>
<th>Pinto peanut</th>
<th>Desmodium, clover</th>
<th>Crota, cajan</th>
<th>Oat</th>
<th>Ryegrass</th>
<th>Brachiaria</th>
<th>Kikuyu</th>
<th>Fodder radish, lupin</th>
<th>Vegetable crops, potato</th>
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<tbody>
<tr>
<td>Rice</td>
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<tr>
<td>Maize</td>
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<tr>
<td>Wheat, barley</td>
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<tr>
<td>Soybean, bean</td>
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<td>Pinto peanut, bamba groundnut</td>
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</table>

**++** Very interesting crop association and easy to manage
+ Rather interesting crop association, but demands a specific crop management
□ □ Very interesting crop succession (possible in every environment)
□ Interesting crop succession cropping (only possible in lowland areas)
Empty : Crop association or succession with little interest and/or difficult to manage
— Crop association or succession very difficult to manage or impossible (incompatible plants)
**Example of selection in the highlands**

In the highlands, in rice fields with poor water control, water conditions can allow off-season cropping, as long as you choose undemanding species in terms of temperature and frost resistant. After the rice crop, you can grow a winter cereal (wheat, barley, oats), which can also be associated with a legume such as vetch (interesting for nitrogen fixation). Besides the additional production of grains, off-season cropping allows producing high biomass, which is used to prepare direct seeding for the next season.

**Table 7. Possibilities of crop association and intra-annual succession of the main crops grown in medium altitude (Lake Alaotra and Mid-Eastern region)**

<table>
<thead>
<tr>
<th>Soybean, bean</th>
<th>Vetch</th>
<th>Desmodium, clover</th>
<th>Crotalaria</th>
<th>Oats</th>
<th>Ryegrass</th>
<th>Kikuyu</th>
<th>Fodder radish, lupin</th>
<th>Vegetable crops, potato</th>
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</thead>
<tbody>
<tr>
<td>Rice</td>
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<td>Maize</td>
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<tr>
<td>Wheat, barley</td>
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Empty : Crop association or succession with little interest and/or difficult to manage
— Crop association or succession very difficult to manage or impossible (incompatible plants)

**Crop association and succession in humid tropical climate (East Coast)**

In a hot and humid climate, the main crop association or succession constraints are often: i) the excess of water (waterlogging, flooding), which restricts possible crops, especially in lowland areas and, ii) the hydromorphic soils, the extremely low fertility of soils, and the very high acidity of organic matter.

High water availability and temperature allow crop associations or successions in a plot. However, if biomass production is high, organic matter mine-
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

Example of selection in semi-arid climate

In the hydromorphic taney of the East Coast, rice is the only feasible crop. In order to avoid monocropping, it is necessary to introduce a legume into the system. Only stylosanthes guianensis supports these hydromorphic conditions. Rice can be associated with the stylosanthes that will grow throughout the year. If biomass production is enough, rice can be reseeded over the stylosanthes cover in the following year, or after two years, which allows soil enrichment and weed control.

Table 8. Possibilities of crop association and intra-annual succession of the main crops grown in humid tropical zone (East Coast)

| Crop association and succession in semi-arid climate, with a dry season of 7 to 8 months (South West) or a very long dry season with very uncertain rainfall (Great South) |
|---|---|---|---|---|---|---|
| Cowpea | Bean | Bambara groundnut | Mucuna | Stylosanthes | Pinto peanut | Brachiaria |
| Rice | ++ | ++ | ++ | ++ | ++ | ++ |
| Maize, sorghum | ++ | ++ | ++ | ++ | ++ | ++ |
| Fruit trees, coffee | ++ | ++ | ++ | ++ | ++ | ++ |
| Cassava | ++ | ++ | ++ | ++ | ++ | ++ |
| Sweet potato | ++ | ++ | ++ | ++ | ++ | ++ |

++ Very interesting crop association and easy to manage
+ Rather interesting crop association, but demands a specific crop management
Interesting crop succession cropping (only possible in lowland areas)
Empty : Crop association or succession with little interest and/or difficult to manage
— Crop association or succession very difficult to manage or impossible (incompatible plants)

Example of selection in semi-arid climate

On the sandy soils of the South West, maize and sorghum are the dominant cereals. Both can be associated with food legumes, twining plants (which allow a significant increasing of biomass production) or not, which produce additional income. Their biomass slowly decomposes in these environments, direct seeding is possible from the following year, either with the same plants or with cotton (which is an interesting cash crop). If there is a high risk of straying animals, cereals can be associated with crotalaria, which is not consumed and thus biomass can be maintained on the plot.
Establishment of direct seeding cropping systems
Selection of crops, crop associations and crop successions

If biomass production is limited in these environments, mineralization is also low throughout the dry season. DMC systems can be efficient with a much lower biomass than in humid tropical climate. When decomposition is low, it is still possible to build systems with high biomass production only every two years, and the second year can be devoted to a crop with high economic interest (such as cotton), but with low agricultural interest because of its low biomass production.

Table 9. Possibilities of crop association and intra-annual succession of main crops grown in semiarid zone (Great South and South West)

| Cover plant (styrlosanthes) allowing soil improvement |

Thus, for each agro-ecological zone of Madagascar, the tables present the feasible crop associations or successions of main crops with the main cover plants, which allows the identification of the most interesting systems to rapidly overcome the main agronomic constraints. Inter-annual successions allow entering into cropping systems, plants with different agronomic and/or economic interests, which allow the favourable improvement of the soil and an increase in farmers’ income. Inter-annual successions, which are easy to manage, are only possible if water availability and temperature are favourable. Some crop associations are easy to manage, but others need a specific operational sequence (seeding date, density, depth and distance, eventual localized placement of fertilizer, choice of varieties, herbicide input, etc.), adapted to climatic conditions, soil fertility level and associated plants.
Volume II. Chapter 2
Selection of the operational sequences

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Establishment of direct seeding cropping systems  
Selection of the operational sequences

1. Selection of the most suitable operational sequence for any given situation

Operational sequence is «the logical and organized combination of techniques implemented on a plot in order to obtain crop production.»

It is made up of the following operations:
- plot preparation (possible soil tillage in year «zero» of DMC preparation, cover crop management, mulching, soil smouldering, etc.);
- seeding (including variety selection and seed treatment);
- application of phytosanitary products (herbicides, insecticides, fungicides);
- weeding (in year «zero») or pulling weeds;
- application of mineral or organic fertilizers;
- harvesting;
- post-harvest practices to prepare for the next cropping season.

All these operations are based on interactions with the aim to optimize production (in relation to objectives and resources), by ensuring a good supply of water and nutrients to crops (and eventually to associated plants), placing them in good conditions so allowing them to capture solar radiation and minimizing attacks by pests. The achievement of these objectives requires in particular:
- obtaining and maintaining a good soil structure (which allows water infiltration and storage, and deep rooting of plants);
- a balanced and regular supply of nutrients;
- weed control (competition for water, nutrients and light is very damaging to crops).

In direct seeding mulch-based cropping systems (DMC), fertility (in the broad sense, includes soil structure, water and mineral supply), weed and pest management is done primarily by the cropping systems. These systems are chosen to fulfil several ecosystem functions and to allow the proper functioning of soil (especially in biological terms), ensured by a significant and rapid return of organic matter.

To be efficient, these cropping systems must produce high biomass (aerial and root), particularly during the first years under DMC. For this, operational sequences must be adapted to local conditions (agronomic units, farm and terroir characteristics) in order to optimize grain (or tubers) and total biomass production.

Thus, the selection of systems (cf. Chapter 1. Volume II) and operational sequences is based on the following relations: the possible operational sequence depends on the cropping systems because crop associations and successions are decisive for the choice of the cultivation operations. On the other hand, the choice of the cropping system is influenced by the different possible operational sequences, which must:
- be compatible with the resources that can be used by farmers (inputs, work, risk, etc.);
- have the capacities that allow the achievement of the established objectives (cf. Volume II. Chapter 1.) in terms of production (grains, tubers, forages), costs, risk limitation, but also in terms of production and restitution of sufficient and diversified biomass in order to allow DMC proper agricultural functioning.
The selection of the cropping system and the operational sequence in a given situation (agronomic unit, farm and terroir characteristics) is based on DMC operating principles and on decision criteria and rules. These criteria and rules will be applied in the same way during the first year of operation (year «zero» to prepare the seed bed for DMC establishment), and in the following years. Decision criteria and rules are the same but operational sequences vary widely. In DMC systems installed on a high biomass, essential ecosystem functions are ensured by the plants and by the biological activity. During the transition year (or years), which corresponds to the time needed by DMC systems to fulfil these fundamental functions, they must be ensured by the operational sequence. Thus, after year «zero» (or years) for preparing DMC, the situations encountered are (usually) different because of the action of the systems installed to prepare for direct seeding; these should have eliminated the main constraints: higher biomass availability, absence of perennial weeds, reduced compaction, etc.

If a suitable soil structure was not obtained in year «zero» (both superficial and deep) for direct seeding, if perennial plants have not been properly controlled and/or if produced biomass (and maintained on the plot) is not sufficient to adequately control weeds, we must consider that we are still in year «zero» of direct seeding preparation to decide the cropping systems and the operational sequences to be applied. If from the beginning of the intervention, soil structure is good and available biomass is sufficient, we consider that we are directly in year 1 and can carry out direct seeding on vegetal cover, without needing a year «zero» for DMC preparation. These decision principles used to select cropping systems and associated operational sequences are the same for tanety and for rice fields. The selection of systems and operational sequences is different between the two landscape units (rice fields and tanety) because: rice field fertility is often better, the water regime is different and the weed pressure on rice fields (when groundwater is absent) is general higher than on tanety. It is therefore necessary to take more efficient measures to control them.

Notice

Chapter 2 of Volume II of the practical handbook of direct seeding in Madagascar presents all the information that can help trainers and extension agents to adjust operational sequences to the plot. The diversity of situations, possible systems, the large number of factors to take into account and the multiple interactions make this a complex document. Thus, this chapter requires very attentive reading.

In practice, the implementation of DMC systems in a given situation is much less complex. For any given situation, the prioritization of constraints allows us to determine the most important steps of the operational sequence in order to overcome the most limiting constraints. You just have to consult this handbook’s pages that discuss the aspects related to the given situation.

In order to guide the reader, the layout provides markers about the different stages (colored tabs and title reminders in the margin, common layout) and each major section ends with a summary. Several examples (in red boxes) show comments and general principles (presented in brown boxes).

The first section of this chapter («Selection of the most suitable operational sequence to a given situation») presents general agronomic reminders on operational sequence and is not specific to DMC. The reader can «fly over» it, focusing primarily on examples, closer to DMC practice.
Likewise, these principles are the same for a cultivated plot, or when fallow or abandoned land is recultivated. The only difference lies in the fact that the flora in cultivated plots is usually dominated by annual plants, while fallows are mostly composed of perennial plants which generally produce high biomass.

Finally, operational sequences form a whole. The different cropping operations interact, influencing and being influenced by the other operations. Therefore, the planning of an operational sequence is carried out:

1. in a whole that must be as consistent as possible in order to maintain optimum conditions for plants throughout their cycle (and prepare for the next season);
2. in a very precise way, taking into account several factors that determine the possibilities, the constraints and the requirements of the different cropping operations;
3. by constantly adjusting itself to the evolution of plot conditions (weeds, pests, etc.).

### 1.1. Factors to be taken into account

The selection of an operational sequence is planned for a given cropping system. It is also planned for a given situation: the plot (agronomic unit) and farm characteristics largely determine the constraints, requirements and opportunities. The choice is based on a rapid diagnosis that allows the identification and decides the main constraints to be eliminated first. It must take into account:

- cropping systems and plant associations (page 5);
- climate and water regime (page 6);
- existing vegetation and weed pressure (page 8);
- soil sealing, surface induration and deep soil compaction (page 9);
- soil fertility level (page 10);
- pest pressure (page 10);
- production objectives (page 11);
- commercialization opportunities and expected benefits (page 11);
- risks of failure and acceptable level of risk (page 12);
- access to inputs (page 12);
- availability of workforce and equipment (page 13).

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*Arachis pintoï as living mulch in upland rice*
### Cropping systems and crop associations

The cropping system and especially the plants to use, largely determine the operational sequence. The characteristics of cultivated plants, such as:

- their cycle;
- their initial vigour;
- their growth habit (erect, twining, climbing) and their size;
- seed size;
- possibility of implantation by cuttings (which allow a faster start than seeds);
- their competitiveness in relation to weeds (related to these characteristics and possible allelopathic skills);

have an influence on:

- seeding date;
- seeding method: broadcasting, in holes or rows. (x seeding depth) or by cuttings;
- seeding rate;
- arrangement between plants, in the case of crop association.

These four seeding parameters are adjustable in their interaction, in order to achieve an optimum establishment of crops and associated plants. The requirements of plants regarding fertility not only influence fertilization needs, but also the seeding parameters.

These characteristics of plants to which is added an eventual allelopathic potential determine their ability to dominate weeds (or not) and thus weed control methods to be implemented (previous crop, seeding method, herbicide treatments, etc.).

The different crops have different sensitivities to pests and may or may not require phytosanitary treatment. The cropping system also influences the insect control methods needed: the insertion of plants into crop associations/successions with insecticide or repellent effects reduces insect control needs, and system biodiversity maintains a favourable auxiliary/pest balance.

All these characteristics of cultivated plants and cover plants are specific to species but also to varieties. Some species such as cowpea show a very high varietal variability which allows and makes it necessary to adjust the cropping system in detail, by specifying the varieties used.

### Example of plant characteristics

Plants with big seeds (such as cowpea or mucuna) generally start faster than small seed plants (like stylosanthes). They allow a higher biomass production in a short time, but can lead to competition with the crop in case of crop association.

Similarly, brachiaria propagated by cuttings starts considerably faster than if seeds are sown and produces a high biomass faster. In crop association, to avoid competition with the crop, implementation by cuttings must be done 15 days later than by seeds, or with a larger spacing. As brachiaria seeds are able to germinate when located deep into the soil, they can be seeded at the same time as rice, associated, as long as they are seeded at a 3-4 cm depth in order to delay their emergence.

In a maize + brachiaria association, localised application of fertilizer on maize allows the reduction of the risks of competition with the cover crop, and thus seeding brachiaria earlier or closer to maize.
The choice of the operational sequence is therefore planned for a specific cropping system, and has a decisive influence on the system’s performance: when it is impossible to carry out the cropping operations necessary for a system, this system should be eliminated from the possible choices. Selection of cropping systems is the subject of Chapter 1 of Volume II of this practical handbook. When selecting a system, we must be sure that the necessary resources (inputs, work during critical periods, etc.) are available to carry out the possible operational sequence, for each given situation. If a detailed observation of the operational sequence for a given situation (plot x selected cropping system) shows a blockage that has not been identified during the selection of the cropping system (inputs or adapted seed varieties not available, work force unavailable at an important period, etc.) and cannot be overcome by an adaptation of the operational sequence, we must select another cropping system.

Examples of plant characteristics

A variety of erect cowpea, such as «David» is not likely to compete for light with maize, unlike a climbing variety. It can be associated with upland rice, but because of its short cycle, it must be carefully managed, all the more than soil fertility is limited and rice grows slowly (cowpea seeding with a 15-day delay compared to rice, except in the highlands where its cycle gets longer).

Thanks to its allelopathic skills, a plant such as oats strongly reduces weed pressure and prepares «clean» plots.

Rice varieties Sebota 93 or 101 that have a «closed» habit should be seeded with a narrower spacing between rows than the variety Sebota 1 which has a more spreading habit and therefore covers the soil and shades weeds faster.

In the Malagasy highlands, fodder radish strongly reduces *Heteronychus* sp. pressure on the succeeding crop, and removes the need for insecticide seed treatment.

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Climate and water regime

Climate (precipitation and temperature) and water regime (waterlogging, flooding, position and movement of groundwater, capillary rise, irrigation and drainage possibilities) determine possible cultivation period. Therefore, they have a strong impact on possible systems and also on the operational sequence to implement. They strongly influence the crop and cover plant seeding date because they must provide a good water supply throughout the cycle (without water lack or excess because plants would not stand it) and an adequate temperature that allow the proper development of the plant. The establishment of a cover plant into a crop must be done at least two months before the estimated end of the rainy season and/or the arrival of the cold season, in order that the cover plant can be installed correctly. The shorter the rainy/hot season, the more crop and cover plant should be grown together, and the shorter the possible delay in cover plant establishment. Therefore, above all, plant cohabitation is managed by spatial arrangement (not only the seeding rate but also the arrangement of plants, in double rows, for example) and localized fertilizer application. In
addition, associating a cover plant with a crop in a low-rainfall environment must be done in such a way that prevents excessive competition for water, by using a low plant density.

Thus, climate and water regime directly influence:

- crop cycle timing (seeding date and variety);
- seeding rate and plant spatial arrangement among them;
- irrigation and/or drainage requirements when they are possible;
- soil cover preparation requirements: herbicide application date in climates with a dry season, soil cover control method in frost climates (requirements and herbicide doses).

They influence to a lesser extent (because indirectly):

- the method of seeding (to allow seeding on a particular date);
- the fertilization needed. On the one hand, it must be adapted in order to obtain sufficient biomass production to allow the proper functioning of DMC (climate influencing both production potential and mineralization rate). On the other hand, climate risk has a great influence on the profitability of an expensive fertilizer supply;
- the weed control method to be implemented (the type of flora and weed pressure being influenced by the climate and water regime).

Irrigation, when possible, can partially eliminate water constraints and overcome the major climate constraints. It offers many possibilities of crop association and succession, allowing crop establishment for a longer period. It also helps to control weeds (submersion irrigation) and some insects. In this case, we try to optimize production, in order to cover the high costs of this practice, especially by adapting fertilization.

### Examples of climate influence

In the humid Southeastern region of Madagascar, the system that associates cassava and brachiaria, on compacted soils, can easily double cassava yields and is very easy to manage. Brachiaria can be seeded before, during or after cassava planting. In Lake Alaotra, and even more in the South West, due to the pronounced dry season, the same system requires the introduction of brachiaria a few months after cassava, at the beginning of the rainy season (otherwise the strong competition of brachiaria for water may cause a decline in cassava production).

In the highlands, it is possible to seed oats, by using the broadcast seeding method, into soybean before it loses its leaves (rather than seeding in holes after harvesting). This practice provides a better biomass production of oats before the arrival of cold season.

Still in the highlands, but in rice fields, drainage at the end of the rainy season allows the establishment of vetch faster (as it does not support waterlogging), and consequently significantly increasing its production.

In the South West, the strong climatic uncertainty makes it difficult to invest in fertilizers because it is risky. Very early seeding reduces this risk and increases the interest to provide fertilization. On the contrary, the application of fertilizer is too risky when seeding late.
Established vegetation and weed pressure

The study of the established flora is crucial in the decision process with regard to the operational sequence. It requires the knowledge of the main species present in the different environments in Madagascar (cf. Annex 1) and provides information about environment (soil fertility, compaction, water regime, etc.). The type of plants and the amount of biomass available are decisive when choosing the operational sequence, and in particular:

- plot preparation - must be adjusted according to available biomass and abundance and type of perennial plants;
- all practices designed in interactions to control weeds: cropping system selection, soil preparation, seeding methods (variety, date, rate, etc.), herbicide treatment, water submersion, etc.

The presence of perennial plants and annual weed pressure (very strong in certain environments such as rice fields with poor water management) must be known in order to manage their control better. It is particularly important to know the type of existing weeds (for example, grasses such as *Ischaemum rugosum*, sedges or broadleaf plants) and herbicides appropriate to crops, as well as their action on different plants.

Examples of vegetation influence

The presence of perennial plants, such as *Cynodon dactylon*, requires the use of a total herbicide, even in case of soil tillage. When well developed, these perennial plants are often indicative of a well-structured soil (as a result of their strong root system), which can be cropped directly without tillage.

Growing crops in a thick mulch, composed of cover plants that eliminate the other species, allows a good weed control without any special measures. When the cover plant used can be controlled mechanically (such as *Stylosanthes guianensis*), the system allows controlling weeds without herbicide, and reducing the working time needed to cover plant preparation.

The high biomass available in the nearby (unburned fallows) can allow mulching the plot on year «zero» or performing soil smouldering.

Vegetation type:
- Presence of perennial plants
- Pressure of annual plants

Amount of available biomass

Plot preparation:
- Previous crop
- Tillage
- Herbicide application

Seeding method:
- (date, density, varieties, etc.)
- Herbicide treatment
- Water submersion

Ischaemum rugosum strong infestation in rice fields
Photo: K. Naudin
**Soil sealing, surface induration and deep compaction**

Under the impact of rain, soils rich in fine particles, but not colloidal, tend to form a thin surface crust called «sealing crust». Furthermore, after heavy rains, very unstructured soils (in particular after soil tillage into small particles) can indurate up to several centimetres at the surface. In both cases, the result is a surface induration, creating an impermeable and very “suffocating” layer.

Sealing and surface induration phenomena determine tillage needs. Unlike deep compaction which is a relatively stable state or that progresses slowly, sealing or surface induration create a state that changes quickly and leads to crop asphyxiation. Soils which are not sealed that look very indurated at the surface during the dry season can change very quickly with the first rains and lose their indurated character before seeding. It is therefore important to assess the level of soil induration at seeding, in order to determine whether tillage is necessary or not. Maintaining the vegetal cover on the plot allows controlling these phenomena that therefore quickly disappear under DMC.

Deep compaction may be solved by subsoiling. However, this practice, requires considerable resources for example, a powerful tractor or bulldozer, subsoiler, which are very rare in Madagascar and very expensive. It is better to eliminate this constraint by choosing systems that predominantly include plants capable to decompact the soil naturally thanks to the strength of their root system and ability to revive biological activity.

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**Example of sealing**

The farmers of Lake Alaotra are familiar with the sealing phenomenon, especially in *baiboho*. They know that in these situations soil tillage (coarse, in order to avoid soil destructuring) is essential, and seek to continuously break the sealing crust. They perform tillage before seeding (minimum tillage at the seed hole level for off-season crops after irrigated rice), and during weeding.

**Example of compaction**

Soil compaction limits the deep rooting of plants, especially those that require good macroporosity like upland rice. Besides the impact on plant nutrition, weak rooting systems make crops extremely susceptible to drought. It is therefore risky to plant upland rice on a compacted soil in an environment with a short rainy season, as in the Mid-West of Madagascar.

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**Superficial tillage in sealed soil to break the crust**

*Photo: K. Naudin*

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**Plot preparation:**

- Soil tillage
- Cover plants and mulching

**Cropping system**

- Sealing, surface induration
- Deep compaction
Establishment of direct seeding cropping systems
Selection of the operational sequences

**Soil fertility level**

Soil fertility level has a direct impact on possible crops and fertilization levels (including micro-nutrients) to provide for any given crop and a given yield objective. It directly influences the optimum seeding rate. Through its influence on the type of flora and weed pressure, it indirectly influences the methods to be used for weed control.

**Examples of fertility influence**

Demanding plants such as rice and maize, cannot be grown on poor soils without using practices to increase fertility: soil smouldering, high biomass with high functional biodiversity including the presence of legumes, mineral fertilizers, etc.

In rich baiboho of Lake Alaotra, the pressure of weeds like cyperus is particularly high. It jeopardizes rice cropping if effective control measures are not taken.

**Pest pressure**

Pest pressure (soil and/or leaf insects, mushrooms, rats and slugs, etc.) may require particular control methods - choice of systems, choice of varieties tolerant or resistant, seed treatment, foliar application, use of entomopathogens, water submersion, etc.

Indirectly, pest pressure influences intensification level: in particular, chemical fertilizer input is only profitable if pest control can be properly insured.

**Examples of insect influence**

The pressure of *Heteronychus* sp. is particularly strong in plots near plains at the beginning of the rainy season when insects escape the rising waters of the downstream plots. The introduction of forage radish or vetch systems can greatly reduce this pressure, likewise using entomopathogens like *Metarhizium anisopliae*.

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*Stem borer on maize*
Photo: L. Séguy
Production objectives
The objectives of production (targeted production levels), and therefore the selected cropping systems and the desired level of intensification, directly determine the level of fertilizer input, the varieties, the seeding rate and the method used to control weeds and insects. This production target is itself based on the farmer’s situation and on his resources, plot characteristics, weed, insect and pests pressure, but also on his desire to take the risk of intensifying (level of risk, commercialization possibilities and conditions, etc.) and on the farmer’s propensity to take risks.

Commercialization opportunities and expected benefits
Commercialization opportunities influence the choice of cropping systems and operational sequences. It can be extremely interesting to modify crop timing and/or use short cycle varieties to allow production during a period of feed shortage where selling prices are particularly attractive (or own consumption requirements are important) and largely compensate for a possible decrease in production. Similarly, seed production (sometimes in the off-season) can be an alternative revenue opportunity which can justify a major investment and crop timing change.

Examples of production objectives
In Lake Alaotra, in order to respond to the fall in the price of maize (related to production increase), farmers reduced their production objectives (and consequently their inputs), except those who were able to add-value to maize through pig farming.

Examples of expected benefits
In the South-East, seeding short cycle upland rice (type B22) in lowlands allows harvesting from January, in the middle of a shortage period, when rice prices are very high.

A farmer who must give part of his harvest to the landowner (often 30-50%) earns only a part of the fertilization benefit which is always risky and only has an interest to invest if the expected income is very significant. Similarly, the purchase of inputs on credit decreases profits, particularly when rates are high as in Madagascar, where credit for an agricultural year «costs» more than 15-20%.
Establishment of direct seeding cropping systems
Selection of the operational sequences

**Failure risks and acceptable level of risk**

The risk of failure and the tolerable level of risk by the farm are key factors in decision making on cropping systems, in the choice of the level of intensification and operational sequence (crop cycle timing, and particularly harvest). These risks can be of all sorts: climatic (drought, hail, cyclone, etc.), phytosanitary (uncontrollable insect attacks, fungal diseases, etc.), technical (failure to keep to an operational sequence because of unexpected constraints, etc.), security (theft), land, etc.

The farmer’s strategy is most of the time based on minimizing risk, all the more than their situation is precarious and their ability to support failure is low. For farms that can afford to take a risk, the greater the income expectation, the higher the accepted risk.

**Examples of risk**

In the highlands, farmers often plant cassava at very high density (30 cm x 30 cm) and harvest small tubers in order to increase the length of harvest time, which makes it less attractive and less risky in terms of theft before harvest, which is frequent around villages.

Around Antsirabe, some farmers harvest rice before it reaches full maturity in order to avoid the risk posed by hail storms, which are frequent during this period, or a pre-harvest theft would make them lose a significant part of their production.

In the South-East, where cyclone risks are significant from January to April, the traditional rice cultivation period in the lowlands, it is possible to produce a short cycle rice under rainfed conditions from September, in order to harvest before the cyclone season.

In Lake Alaotra and in the Mid-Eastern region where the rainy season is relatively short, investing in fertilizers is a risk that can be very profitable, as long as you seed after the first rains (therefore, limiting high climate risk) and control soil insects and weeds.

If seeding is done later and insects and weeds are not controlled, the risk is too high and is not recommended.

**Examples of access to inputs**

The inability to access fertilizers to cultivate rice on poor soils makes it necessary to use soil smouldering practices (which do not require financial investment if the manpower and biomass are available).

Throughout Madagascar, the access to a total herbicide (like glyphosate) allows the cropping (preferably legumes) by direct seeding on a living mulch of *Cynodon dactylon* without tillage and with very little weeding.

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**Access to inputs**

The possibilities to access inputs (availability, cost and means of purchase) also have a direct impact on operational sequence (and on the choice of system). The availability of fertilizers directly determines fertilization possibilities, the access to herbicides directly affects plot preparation methods and weed control, and the access to pesticides influences pest control possibilities.

Using credit to finance investment (particularly fertilizers) reduces the benefit of possible intensification and makes it less attractive.
Establishment of direct seeding cropping systems
Selection of the operational sequences

Availability of work force and equipment
The availability of a work force at key periods (for plot preparation, seeding, weeding, harvesting) largely determines the cropping practices (plot preparation and seeding method and date, weed control method: broadcast seeding rather than transplanting or row seeding to reduce working time, or using herbicides to reduce weeding time, etc.). Indirectly, where it is impossible to carry out certain tasks such as plot preparation and weeding on time, due to a lack of work force (and/or financial resources to hire work force) or equipment, it influences fertilization level, as well as system selection.

In the case of low availability of work force (family or employed), adequate equipment can greatly reduce work time (seeders, weeder, knife roller, etc.). The same is true for the use of inputs (herbicides in particular) or water submersion for weed control when possible.

Examples of work force
In the highlands where farmers give priority to rice fields (which generally ensure their rice production), upland rice is often seeded very late (after the establishment of rice fields). Direct seeding into straw can be done under dry conditions, before the arrival of the first rains, and thus enables a very early start of rainfed crops, without delaying implementation into rice fields.

In the Mid-West, where farmers have relatively large areas (usually 5-10 ha, cultivated manually), the preparation of a stylosanthes mulch is done at the end of the dry season, a period when man power is available. It greatly reduces weeding work and helps to maintain clean plots, despite the low availability of man power during the cultivation period.

1.2. Interaction between factors and cropping operations. Selection of operational sequence
The selection of possible operational sequences for a given system is based on these different factors in interaction. Some factors have a direct influence on the operational sequence (access to inputs, for example), while others have an indirect effect (climate for example, which influences weed flora, and plays an indirect role on the choice of the weed control method to be implemented). Some factors can be controlled (for example, fertilizer input to increase plot fertility) while others are difficult to control (climate, for example). The adjustment of the operational sequence is based on prioritization of the most important factors for each situation, using controllable factors in order to adapt to uncontrolled parameters.
Interaction between factors and cropping operations

In general, the operational sequence must ensure a certain number of agronomic functions during the first year(s), the period needed to ensure these functions by multifunctional plants and high biological activity. Once the DMC systems are properly installed, the operational sequence is simpler. The agronomic functions are mainly ensured by plants and biological activity. Thus, even if criteria and decision rules are the same in both cases, the operational sequence is very different between the first year(s) of DMC preparation and the following years, in well-established DMC systems:

- soil structure is ensured by the biological activity of the systems established under DMC. However, a mechanical tillage is often necessary on year «zero» of DMC preparation;
- in year «zero», plot preparation must enable the control of perennial weeds, so, that once the DMC system is installed, we just need to control the vegetation cover;
- in year «zero» the control of annual weeds requires a certain number of procedures that combine different practices (tillage, mulching, early seeding, species and use of varieties that can quickly cover the soil, high seeding rates, use of selective herbicides or total herbicides applied locally and/or removing weeds, etc.) while it is mainly ensured by the vegetation cover in installed DMC systems, and demands only minimal work. In all cases, plot weeding should be avoided, as much as possible, because it disturbs soil and relocates weed seeds in good conditions for germination. However, under certain conditions where there are severe constraints on weed control during year «zero», weeding may be the only solution available to farmers. It must be performed by trying to minimize soil disturbance as much as possible;
- fertility must be restored in different ways (mineral or organic fertilizers, amendments, soil smouldering, «biological pump», etc.) during the first years of direct seeding preparation, while it is simply managed in well-established DMC systems (compensation of exports by harvested forage);
- once an ecological balance has been established and plants have a better water and nutrient supply in well-established DMC systems, pest control measures (and particularly phytosanitary treatments) are not as necessary as in the early years.

The operational sequence for a given plot forms a whole, where different components (plot preparation, seeding, application of phytosanitary products, fertilization, harvesting) are linked, influencing and being influenced by the other components of the operational sequence.

Even if the farmer is committed to an operational sequence planned in advance, its implementation on a complete crop cycle must continually adapt to cope with unexpected situations. It should allow cultivated plants to grow in the best possible conditions: access to light, water and nutrients, without competition from weeds or strong attacks by insects or diseases. Thus, the operational sequence must also be adjusted regularly, which requires careful monitoring and a quick response to change.

Each stage of the operational sequence offers several possibilities and needs to be adjusted according to:
- the overall operational sequence; and
- the state of the plot and crop after the effective performance of the previous stages.
2. Plot preparation before seeding

Plot preparation aims to allow seeding in optimum conditions for the proper germination and growth of young plants. This is a key step particularly in weed control that must enable the establishment of young plants in «clean» plots, free of weeds.

Soil fertility (and the resources to improve it), selected crops and production objectives may lead to the use of soil smouldering practices, which allow an increase in soil fertility and serve as plot preparation (with a localized and deep tillage that may give rise eventually to deep soil compaction).

In the absence of soil smouldering, soil preparation may or may not require soil tillage during year «zero» of DMC preparation.

In established DMC systems, tillage must be avoided at all costs because it causes a rapid loss of the improvements achieved through direct seeding practices. Therefore, plot preparation consists only of plant cover control.

In all cases, the main factor that determines plot preparation possibilities and requirements is the amount of available biomass, which can be estimated visually.

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**Plot preparation: soil smouldering**

Soil smouldering is an interesting alternative to growing demanding plants on poor soils, or to achieve high production objectives while minimizing chemical inputs, as long as manpower and biomass are available.

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**Plot preparation: available biomass**

**High amount of available biomass:**

No tillage: control of vegetation cover by herbicide use, peeling off with an angady, mowing, passing over with a knife roller or rotary shredder.

Biomass production at the edge of plots or in uncultivated neighbouring plots allows the easy importation of a high biomass and thus quickly initiates the direct seeding «pump», even on poor soils. This biomass can also be used for soil smouldering.

**Low amount of available biomass** (on year “zero” of direct seeding preparation):

- tillage, to reduce weed pressure; or
- control of vegetation cover by herbicide use, peeling off with an angady, mowing, passage with a knife roller or rotary shredder, for direct seeding crops that allow easy weed control. Forecast weed control during vegetative growth (using post-emergence herbicide, hand-pulling, water submersion, etc.).

**Limits:** below 5 tons of dry matter/ha (about 5 times more than for green matter), the soil cover is often insufficient to control weeds properly. From 7 tons of dry matter/ha, the soil cover is usually sufficient for proper weed control (unless the cover is composed of cereals with thick stems, such as maize or sorghum).

However, weed control throughout the cropping cycle depends on many parameters, such as:

- quality of biomass and therefore its decomposition rate: rapid decomposition for a low C:N ratio like mucuna leaves, slow for a high C:N ratio like sorghum cane;
- straw type and mulching structure: thin straws like brachiaria and aristida are better for covering the soil but decompose faster than larger straws (such as maize or sorghum stems) or than a mulch with a multi-layered structure (styrlosanthes, «liana» legumes), wherein the contact with soil is done gradually, layer by layer, slowing decomposition;
- climate: heat and humidity, as in the South East, accelerate cover decomposition;
- soil coverage rate by the cultivated crop, which depends on the plant’s cycle and habit, density, seeding date (related to the beginning of the rains that stimulate weed germination) and plot fertility level: a crop that quickly covers the soil, like maize + cowpea association, controls the weeds grown through an insufficient mulching, unlike a long cycle rice seeded at low density;
- weed pressure and type of flora: some plants like oxalis, centellas, commelinas and euphorbia are able to pass through a thick mulch.
Estimation of standing biomass (dry matter)

Crop residues (maize + dolichos bean)

4-5 t/ha
7-8 t/ha
> 15 t/ha

Crop residues (maize, rice, oats)

Maize, 7 - 8 t/ha
Rice, 5-6 t/ha
Oats, 6-7 t/ha

Stylosanthes

< 2 t/ha
6-7 t/ha
> 12 t/ha
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Estimation of biomass on the ground (dry matter)
(Photos: G. Soutou - K. Naudin)

Herbaceous grass (Andropogon)

2 ton/ha. Soil coverage: 90%
Thickness: 1 cm

5 ton/ha. Soil coverage: 99%
Thickness: 3 cm

10 ton/ha. Soil coverage: 99%
Thickness: 6 cm

50% herbaceous grass (brachiaria) + 50% sorghum

2 ton/ha. Soil coverage: 60%
Thickness: <1 cm

5 ton/ha. Soil coverage: 80%
Thickness: 1 cm

10 ton/ha. Soil coverage: 99%
Thickness: 3 cm

Sorghum

2 ton/ha. Soil coverage: 20%

5 ton/ha. Soil coverage: 45%

10 ton/ha. Soil coverage: 70%
In year «zero» of direct seeding preparation, the available biomass on small family farming plots is often insufficient to allow direct seeding. Sometimes, in year «zero» we cannot produce and maintain sufficient biomass for a direct seeding under good conditions, with good weed control. In such cases it is advisable to concentrate the biomass available on the part of the plot that is going to be conducted under direct seeding (on an adequate plant cover), and to consider the rest of the plot, where biomass has been removed, as being in year «zero». In all cases, a system with very high production of biomass must be repeated to initiate the DMC "pump".

It is also of interest to try to produce high biomass on the edge (living fences, erosion control lines) or near the plots (on fallows), which allows the «recharge» of biomass in the plots that had insufficient production.

The second parameter to consider is the presence, abundance and type of perennial plants on the plot. These factors determine the need for herbicides and tillage usefulness. A perennial plant already established represents high competition risk with an annual plant (crop), even if it has been mowed or tilled which favours the spread of plants with rhizomes:
- generally, its vegetative growth starts faster than in sowed annual plants (especially those with small seeds), which means that the perennial plant quickly shadows the crop;
- its root system is often more powerful and deeper than the annual plant and is already deeply established, which creates strong competition for water and nutrients.

Moreover, these perennial plants are rarely controlled by selective herbicides and their control during the cropping period, is difficult even by weeding.

It is therefore essential to eliminate perennial plants before crop establishment, or at least to control them during the cropping period, as in the case of crops on living coverage.

Erect perennial plants, that produce no or just a few rhizomes can be quite easily controlled by peeling off with an angady (i.e; cutting the roots horizontally a few centimetres below the soil surface and thus cutting fine layers of the top soil, leaving them in the same position to minimize soil disturbance) and especially if they are scarce and scattered. However, creeping plants and/or plants that produce many rhizomes or stolons are difficult to control mechanically, and this work may cause considerable soil disturbance.

During year «zero» of DMC preparation, on low biomass plots, another important parameter to consider is soil sealing or surface induration.

### Plot preparation: control of perennial plants

#### When perennials are abundant:
- use of a total herbicide after vegetation regrowth or at the end of the previous rainy season in order to control (systems on living mulch using perennial plants like cynodon) or to kill (dead cover systems) perennial plants;

or for erect plants, which are easy to control:
- peeling off with an angady at the beginning of the dry season (this is very time consuming and can disturb the soil);

or alternatively, in the absence of herbicide:
- tillage at the beginning of the dry season and exposure of the roots and rhizomes to sunlight. A second tillage before seeding and hand-pulling the living plants. Manual labor demand is lower than for peeling off with an angady but soil disturbance and erosion risks are higher;

#### When perennials are absent, scattered or easy to control manually:
- peeling off with an angady; or
- localized application of total herbicide.

**Angady**: sort of spade (Malagasy word)
In the case where the soil presents such a hardened surface, it is essential to till it (roughly to avoid further induration). During the following years the mulch that is maintained on the soil under DMC prevents any induration or sealing phenomenon.

Deep soil compaction is a very important parameter when selecting the crops, crop associations and crop successions to be established during the initial year(s) by favouring the plants with high restructuring power, but it doesn’t have much influence on the choice of the operational sequence, except:

- when the farmer takes the risk of establishing a crop sensitive to compaction without deep tillage, in which case inputs are limited to reduce risk taking (but it doesn’t influence plot preparation);
- when it is decided to carry out subsoiling (difficult to implement in Madagascar and in any case extremely expensive) to install a crop with high economic value, which will cover the costs of implementation.

The effective accomplishment of plot preparation depends on the selection of the operational sequence, but also:

- on the climate and water regime of the plot that influence soil tillage date (year «zero») or herbicide treatment of plants during vegetative stage;
- on the available resources, particularly work force availability and access to equipment and inputs (mainly fertilizers and herbicides);
- on the type of vegetation cover to prepare.

The date of plot preparation should allow seeding after the first rains.

In year «zero», if necessary, soil tillage must sometimes be done at the end of the previous cycle (for example on heavy soils, difficult to till).

In following years, the control of very high biomass vegetation cover must be done very early in order to give it time to pile before seeding. Similarly, a grass-dominated biomass should be prepared some weeks in advance, especially when composed of thick stems which decomposition is slow: if treated too close to seeding period, it is very likely to cause «nitrogen shortage» on the cereals cropped subsequently.

On the other hand, in the case of low biomass, plot preparation should not be done too soon, to maintain a maximum amount of biomass in order to cover soil and to control weeds at the beginning of the cycle. When bio-
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mass is dominated by leguminous plants whose leaves decompose rapidly, plot preparation must be done just before seeding (and can even be done on the day of seeding if using herbicides). Plot preparation affects many farming operations thereafter: it directly influences the seeding date, rate and method, fertilization (effect of soil smouldering or even nitrogen requirements for cereal a crop on a grass mulch), and the method to control weeds and insects (influences of the mulch and the seeding date especially).

In all cases, the preparation of a plot should allow for the plot to be ready to be sown in good conditions. The plot must be checked before seeding.

Plot preparation

In all cases, plot preparation must allow the establishment of crops in plots without weeds when seeding (because they would be in advance relative to crops and be very competitive). Perennial plants that can re-grow after their treatment must be eliminated because they are very difficult to control in direct seeding systems on a dead vegetation cover. To use it in a living cover, you must ensure that their control is sufficient and homogeneous.

For annual plants, we verify that new plants have not started their growth, especially when plot preparation was done long time before seeding. If necessary, additional control work must be done just before (or during) seeding: herbicide use, grubbing, peeling off with an *angady* or eventually light weeding (in year «zero»).

Selection of operational sequence: plot preparation before seeding

| 1 | Identification of deep soil compaction and plot fertility |
| 2 | Selection of crops, crop associations and successions (cf. Vol. II. Chapter 1.), and particular practices |
| **Subsoiling** | **soil smouldering** | **Plot “normal” preparation (no soil smouldering and no subsoiling)** |
| 3 | Identification of available biomass and perennial plants |
| **Low biomass available** | **High biomass available** |
| 4 | Perennial plant control *Page 26* |
| 5 | Deep tillage | Soil smouldering practices *Page 21* |
| 6 | Identification of sealing and induration risks |
| Sealed soil | Non-sealed soil |
| Tillage and coarse crumbling *Page 29* | Tillage and crumbling (only year “zero”) *Page 29* or Herbicide treatment, removing, mowing or rolling *Page 29* |
| 7 | Mulching (recommended) *Page 30* |

Vegetal cover control (according to flora type) *Page 31*
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2.1. Soil smouldering

The interests of soil smouldering
Soil smouldering is a technique used to quickly release the fertility «trapped» in soils, by slow combustion. It is particularly efficient on soils where organic matter develops slowly due to the acidity of the soil (very common in Malagasy soils), the frequent presence of allophanes, low temperatures (in the case of the highlands) and/or hydromorphic soils (as in the poorly drained rice fields or in the South East of Madagascar).

The main effects of soil smouldering are:
- oxidation of acidic organic matter, trapping of nutrients;
- acceleration of mineralization and release of nutrients, particularly the bases: Ca, Mg, K;
- pH increase (possible to gain one unit);
- release of large amounts of assimilable phosphorus, which was linked to organic matter and fixed by aluminium (Al3+, dominant form with very low pH);
- reduction of weed stock in burned soil;
- good rooting of plants that benefit from deep tillage.

Low temperature (200 - 300°C) combustion «by suffocation» avoid mineral loss by volatilization (especially N). Biological activity, destroyed by burning at trench level is rapidly reconstituted and increased (in a few weeks), in a more favourable environment.

Soil smouldering practice is a very interesting alternative in the case where there is little access to fertilizers (because of high prices, difficult to transport, etc.), and for an agriculture that aims to minimize financial investment. It requires no special equipment and its preparation is done during the dry season. It only requires a financial investment if hiring a work force or if biomass must be purchased or transported over long distances (which greatly reduces any interest in this practice).

Its effect is visible for several years and, combined with mineral fertilizers, it allows the achievement of high production levels (under intensive farming).

However, this practice requires a lot of work, some skill and a high amount of biomass to burn. These constraints can limit its practice.

Precautions and limits of soil smouldering
Soil smouldering practice burns a portion of the soil’s organic matter. Its effect is more marked if the soil’s organic matter level is higher. Soil smouldering should not be performed on a soil with less than 1.5% of organic matter, nor repeated on the same row in two consecutive years. After soil smouldering, direct seeding systems must be practiced with a high biomass return in order to restore the burnt organic matter.

soil smouldering performance

Preparation of biomass to be burned
The preparation of the biomass that will be burned by soil smouldering represents a lot of work, carried out during the dry season.

The selection of biomass type
The selection of biomass type is done primarily according to its availability.

When rice straw is available, it is very desirable because of its richness in silica (which confers resistance to pests, lodging and drought).

Rice husks are also of interest and even richer in silica than straw. It is generally free from rice mills, but requires transportation, which can be problematic due to the high volume. It cannot be used alone because it does not allow good circulation of air and has a slow combustion.

Natural vegetation has the advantage of being readily available. Aristida has a slow combustion, and requires large amounts (this means mowing large areas, but the production per hectare is limited).

Shrubs like mimosa (Acacia sp.) have a rapid combustion and provide nitrogen.
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The shorter the dry season (as in the South East), the faster this work must be done. A «medium» soil smouldering requires 30-40 tons of dry matter/ha, with a minimum of 20 t/ha and a maximum of 60 t/ha for a high performance of soil smouldering in soils rich in organic matter. Biomass must be mowed, dried for 2-3 days and then transported to the plot where the soil smouldering will take place. The greater the transport distance, the greater amount of work to be done, which makes it particularly important to produce biomass in advance on the plot (planting shrubs beforehand, such as acacias) or along the borders (Bana grass, for example). In the case of using rice straw, very little work is needed.

Control of perennial plants
When soil smouldering is done on a plot where perennial plants are abundant (Cynodon dactylon fallow, for example), it is necessary to remove these plants before carrying out soil smouldering. Controlling these plants after soil smouldering is very difficult because they will be covered by the soil taken from the trenches, and therefore they won’t be very visible and herbicide will not reach them. The use of herbicides throughout the perennial plant’s growing season facilitates trenching work afterwards. In the case where herbicide is not used, peeling off perennial plants with an angady is possible, but is very time consuming (cf. page 26).

Trench digging
The trenches in which localized soil smouldering will be performed must be dug, preferably, perpendicular to the slope. In the case of the risk of water stagnation (which can generate diseases), drains to eliminate water in the trenches must be made or trenches must be dug in the direction of the slope (on a gentle slope). On steep slopes, soil smouldering practices can be done by performing mini-terraces with several steps. The distance between trenches and their width subsequently determine the seeding rate. Crops are seeded in the trenches of slashed and burned soils.

Trench width is from 20 to 40 cm. Soil smouldering technique is better on wide trenches, but the amount of biomass to be used is higher. A wide trench also facilitates seeding crops such as rice or potatoes in double rows. The distance between trenches (from centre to centre of the trench) is from 80 to 100 cm according to the desired seeding rate afterwards. Trench depth is around 20 cm, except when the organic surface horizon is very thin. In this case, the trench depth is the same as the organic horizon thickness (without digging the lower horizons, which are too poor to be smouldered).

These trenches can be dug with an angady, which is labour intensive but allows:
- performing rectilinear and regular trenches (facilitating trench seeding);
- putting aside the soil with the highest organic matter content, used to cover the trenches, and thus to ensure the good quality of soil smouldering.

Trenches can also be dug with a plough by double passage through the same furrow which allows the opening of a large furrow. Trenches are then finished by using an angady, with much less work (but the trenches are dug in a less precise way).
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Filling the trenches with biomass (fuel)
Trenches are filled with biomass, then well compacted by foot, up to 10-15 cm above ground level. The higher the biomass input, the better the efficiency of combustion and soil smouldering. Straws (rice, bozaka, etc.) are arranged in the direction of the trench in order to facilitate the spread of the fire and air circulation. When using rice husks or branches, where the spread of the fire is more difficult (and rice husks are more difficult to ventilate), a straw layer is installed beforehand at the bottom of the trench and another layer is placed on the top, which facilitates ventilation and spread of the fire. Straw strands are installed every 1.5 m. After covering the trenches straw strands come out of the soil and form chimneys.

Covering trenches with soil
The trenches filled with fuel are then covered with 8-15 cm of soil, by taking care that the soil used is from the surface and is organic (the darkest), and leaving unobstructed straw ventilation chimneys in order to set the fire. According to the amount of fuel supplied, the thickness of soil provided to cover the trenches allows the regulation of «air circulation» and consequently combustion speed and intensity. Less than 8 cm of soil leads to an extremely rapid combustion, at excessively high temperatures (the higher the amount of fuel, the higher the temperature). More than 15 cm makes the combustion difficult (more difficult as the amount of biomass supply is lower), and causes “suffocation” and incomplete combustion risk.

Firing and combustion
Firing is done by straw strands. After firing, combustion is carefully controlled to:
• avoid fire spreading into the surrounding plots or follows;
• ensure a good combustion of all the biomass supplied. Combustion must be complete, but not too quickly (24 to 48 hours, depending on the quantity of biomass supplied, the thickness of soil that covers it, the space between chimneys and the type of biomass), likewise charcoal preparation. In case of the appearance of flames (external to the chimneys), cover it with a bit of soil (organic if possible). If ventilation is poor soil

Covering trenches and implementing chimneys for firing
Photo: N. Moussa

Firing and combustion
Ventilation with angady
Photo: N. Moussa

Plot after combustion
Photo: T. Raharison
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smouldering and the fire may go out, it is possible to lift up the straw and soil by inserting an angady in the chimney and levering.

If combustion stops and there is no possibility to relight the fire through the chimneys (“suffocation” because of too much soil, or lack of fuel, or rain) it is necessary to reopen the trenches, eventually drying the fuel and adding more fuel if necessary, and to restart the soil smouldering process.

A successful soil smouldering is recognizable by the red brick colour of the soil inside the trench.

Note: in case of the absence of straw and the use of branches instead, it is possible to set the fire directly to branches deposited in the trenches and then to cover them with soil once the combustion is well started (being careful not to burn too many branches at a time, in order to be able to cover them before their combustion is complete).

Flattening and controlling annual weeds
After cooling down (2-3 days after finishing the soil smouldering), make sure that there is no unburned buried biomass. Under anaerobic conditions, the buried vegetable matter deteriorates and leads to the production of toxic compounds. It is therefore essential to restart soil smouldering in these places. The unburned fuel can be detected by the fact that the soil on top of the trench has not collapsed, as it is in the places where combustion is complete. Once the combustion is entirely finished, it is necessary to fill the trenches, which are hollowed due to collapse after biomass combustion. Thus, after getting the plot levelled we must take care to properly identify smouldered rows in order to carry out seeding. Levelling the plot also allows the control of annual weeds (perennial weeds having been controlled before) that might regrow between the trenches.

If biomass is still available, mulching smouldered plots is a good idea (weed control, soil protection, organic matter recharge).

### Average work time

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (days/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mowing the required biomass</td>
<td>80 to 100</td>
</tr>
<tr>
<td>• 20 ton/ha</td>
<td>80 to 100</td>
</tr>
<tr>
<td>• 60 ton/ha</td>
<td>240 to 300</td>
</tr>
<tr>
<td>Biomass transport (over 500 m)</td>
<td>80 to 100</td>
</tr>
<tr>
<td>• 20 ton/ha</td>
<td>80 to 100</td>
</tr>
<tr>
<td>• 60 ton/ha</td>
<td>240 to 300</td>
</tr>
<tr>
<td>Digging trenches for soil smouldering</td>
<td>60 to 80</td>
</tr>
<tr>
<td>• with angady</td>
<td>60 to 80</td>
</tr>
<tr>
<td>• with tillage</td>
<td>5 to 8</td>
</tr>
<tr>
<td>Filling trenches</td>
<td>12 to 20</td>
</tr>
<tr>
<td>Covering trenches</td>
<td>6 to 10</td>
</tr>
<tr>
<td>Firing</td>
<td>5 to 6</td>
</tr>
<tr>
<td>Levelling after soil smouldering</td>
<td>4 to 5</td>
</tr>
</tbody>
</table>

**Total working time for soil smouldering:**

**Preparation of biomass:**

• 20 ton/ha of biomass: 160 to 200 days/ha
• 60 ton/ha of biomass: 480 to 600 days/ha

The use of rice straw (already mowed) or biomass produced on the edge of the plot significantly reduces work time.

**Performing soil smouldering:**

• with angady: 85 to 130 days/ha
• with tillage: 30 to 50 days/ha

**Average total time:**

(40 ton/ha of biomass, with angady): 460 days/ha.

This work is done during the dry season (from May to October rain does not allow the fuel to dry nor the practice of soil smouldering). Therefore, one man alone cannot make more than 30 acres per year.

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Smouldered soil, with brick red colour

Potatoes after soil smouldering.

Photo: N. Moussa
2.2. Preparation of plots with low availability of biomass

The year «zero» of direct seeding preparation is often done in plots where biomass availability is low, especially within the context of a small, low-intensive family farm with degraded soils. If it is not possible to import biomass (from nearby) for mulching, the use of tillage is often preferable, particularly to facilitate weed control. It is also possible that a «failure» (due to climatic adversity, poor operational sequence, uncontrolled export of produced biomass, etc.) in plots already under direct seeding practice leads to low availability of biomass. Furthermore, the main problem of a poorer soil function, due to the lack of biomass, is weed control (mainly annual plants). Using tillage all over again should be avoided as much as possible because it has the disadvantage of greatly disturbing soil function (especially mineralization dynamics) and ecological balance which has been «reconstructed» thanks to DMC.

Importation or concentration of straw on the plot

When the biomass available on the plot is low, the importation of straw from the surrounding plots, after soil preparation, is often of interest. This biomass can be taken from natural fallows or produced in advance on the border of plots (by planting previously pennisetum, cajanus and tephrosia hedges). It is better to establish the straw before seeding, although it is also possible (but takes longer to achieve) to «recharge» the plot with biomass after the emergence of crops sown in rows. The optimum amount depends on the climate (mineralization rate), type of vegetal material, weed pressure, biomass already present on the plot, and biomass availability and accessibility.

When the availability of biomass on the plot is low and if it is not available in the neighbourhood, we can concentrate the plot's biomass on part of it in order to reach the amount that allows growing the crop under good conditions, under DMC. The rest of the plot where the vegetation has been removed is then considered as being in year «zero», in order to produce enough biomass for the following year. To avoid transporting biomass from one side of the plot to the other, it is also possible to concentrate the biomass in strips, alternating strips under direct seeding (where biomass was concentrated and on which the main crops will be planted, possibly in double rows) and tilled strips (which will receive the cover plants). The greater the amount of total biomass, the better the effects (soil improvement, weed control) which are very significant from a total biomass of:

- 10-12 ton/ha of dry matter in dry environments (Malagasy South West) or in subtropical highland climate (Malagasy highland);
- 12-15 ton/ha at medium altitude (Lake Alaotra, Mid-West);
- 18-20 ton/ha in warm and humid environments (South East).

When the biomass produced during year «zero» of DMC preparation is not sufficient, and it is not possible to import or concentrate biomass on the plot, the best solution is to carry out, in the following year, a system with high biomass production, under DMC, with a crop easy to weed and in case of heavy weed pressure performing a light weeding, if necessary.
Control of perennial weeds

The control of perennial plants (when they are present) is an essential prerequisite for the establishment of systems under DMC. Depending on the availability of a workforce, on herbicide availability and cost, and on perennial weed abundance, stage of development and characteristics (and thus of the work needed to remove them manually), we can:
- use herbicides when they are accessible and when the available workforce is not sufficient. Perennial plants are usually well controlled with glyphosate used at a dose of 1,800 g/ha for grasses and 2,4-D at a dose of 720-1,080 g/ha for broadleaf weeds. It is possible to use both products mixed when the two types of plants are present. If perennial plants are distributed in bands, the treatment can be localized, which greatly reduces the dosage per hectare and therefore the cost. The use of herbicides is particularly useful for creeping perennials, with rhizomes and/or stolons (particularly *Cynodon dactylon* that is found in different environments and in all ecosystems or *Panicum trichoides* and *Stenotaphrum secondatum* common on the East Coast), which require hard labour (and cause high soil disturbance) when controlled without herbicide;
- prefer mechanical control, by peeling off (no available herbicides, available workforce, scarce perennial weeds). For perennial plants with erect habit and/or tufted (like *Aristida* sp., *Hyparhenia* sp., *Imperata cylindrica*, etc., that are found on tanery), peeling off with an angady is generally sufficient if it is carried out at the beginning of the dry season. The time required to carry out this operation depends primarily on the abundance of perennials. When they are spread out, their control by peeling off is often of interest, but when they are abundant it is not so interesting. Creeping plants with stolons and/or rhizomes are much more difficult to control mechanically and require tillage at the beginning of the dry season, and one more tillage before crop establishment. Total herbicide use (1,800 g/ha of glyphosate) is often preferable when these plants are abundant (and when the herbicide is available).

In order not to delay seeding, the ideal is to treat perennials with an herbicide during the vegetative season, at the end of the previous rainy season (otherwise you must wait for growth recommencement after the first rains, which delays seeding for more than a month) or peeling off with an angady during the dry season.

These two approaches allow good control of perennial plants in numerous situations. However, we might encounter special situations that require a specific treatment.

Reminders on herbicides

The herbicide dose to be applied depends on:
- the species to be treated;
- the abundance of perennial weeds;
- their distribution: the treatment of concentrations of weeds consumes less herbicide per hectare than dispersed plants, and;
- the stage of weeds during application: an old plant is less sensitive than a young plant with a few leaves;
- application conditions: high temperature reduces penetration into plants (as they close their stomata) and thus herbicide effectiveness. Glyphosate has maximum effectiveness at pH 4 and greatly loses its effectiveness when used with alkaline water, etc.

Thus, the doses recommended in this handbook are the average doses corresponding to the ones needed to kill these plants at an intermediate growth stage for a medium and regular level of infestation, and with an herbicide application under normal conditions (cf. Annex I.1.). These doses, which are all expressed in quantity of active substance, must be adjusted according to application conditions.
Establishment of direct seeding cropping systems
Selection of the operational sequences

Perennial grasses found in rice fields
Some rice field grasses such as *Leersia hexandra*, and especially *Oryza longistaminata* (rice with rhizomes) cause serious problems and require special preparation of plots to control them.

- **Leersia hexandra**
  *Leersia hexandra* is difficult to control once the crop is established. It is recommended to kill it before cultivation by using glyphosate (1,080 to 1,800 g/ha depending on the vegetative stage). If there is no control before seeding the control of this weed requires a lot of prolonged weeding.

- **Oryza longistaminata**
  Rice with rhizomes is a species closely related to cultivated rice. It is difficult to distinguish them at a young stage, which makes hand-weeding impossible. Moreover, for the moment, a rice selective herbicide does not exist that is efficient on this wild rice.
  The only efficient control method consists in killing it with a high dose of total herbicide (glyphosate at 2,160 g/ha) and at a sensitive stage just before flowering. This can be done on an abandoned plot due to a heavy infestation by *Oryza longistaminata*, to prepare it for the following year. In less infested plots, this can also be done by killing *Oryza longistaminata* locally on the groups where it appears. However, this practice has the disadvantage of also killing the cultivated rice, unless if the variety used has a very short cycle and can be harvested (panicle per panicle) before *Oryza longistaminata*’s flowering stage. In this case we apply the herbicide on *Oryza longistaminata* just after rice harvest.
  The biomass obtained from *Oryza longistaminata* is usually sufficient to be used as soil cover for direct seeding the next crop (which will grow better without tillage), which is not the case of *Leersia hexandra* or of perennial sedges.

Perennial sedges in rice fields: *Cyperus rotundus and Cyperus esculentus*
Two perennial sedges are particularly troublesome in rice fields: *Cyperus rotundus and Cyperus esculentus* are considered as plant pests all over the world.
Their storage organs allow them to survive during the dry season, to resist many herbicides and to multiply rapidly, especially under the effect of tillage that breaks up bulbils and promotes vegetative propagation.
As for *Oryza longistaminata*, while waiting for an efficient selective herbicide, the best way to control is to apply a total herbicide (glyphosate at 1,800 g/ha) at the end of the rainy season in order to prepare the crop for the following year.
It is also possible to use the properties of some mulches in direct seeding, such as: sorghum coverage (or oats) that due to the prolonged shading of the soil surface combined with allelopathic effects (emission of substances, natural herbicides), control some of these plant pests.
Thus, a cropping system with sorghum production (not photoperiodic) during the dry season, used as a mulch for the following agricultural year may be proposed.
It is also possible to slow down the emergence of Cyperus with a thick mulch (maize + dolichos bean, for example) and then to treat the young weeds with bentazon (380 g/ha) in rice cultivated at high seeding rates.
Establishment of direct seeding cropping systems
Selection of the operational sequences

Plots with perennial rhizomatous weeds, already tilled
In the case where one intervenes on a plot that has been tilled at the end of the rainy season/beginning of the previous dry season, but without previous herbicide application (a frequent practice used by farmers to try to control these perennial weeds, exposing the roots and rhizomes to the sun during the dry season), we must ensure that these plants were well controlled and that the rhizomes will not be able to produce new plants. In the opposite case, we must also wait for vegetation regrowth before applying the herbicide (glyphosate at 1,800 g/ha) and, if necessary, complete soil preparation (new tillage and/or breaking up clumps) once herbicide action is visible.

Burned perennial fallows
The practice of slash-and-burn is common in Madagascar. For re-cropping a perennial fallow that burned (intentionally or accidentally), there is the dual problem of controlling perennial weeds before seeding and then controlling annual weeds in the crop, without mulch.

Most perennial plants are not controlled by fire. Slash-and-burn practice aims to promote their recovery for the production of young leaves during the dry season and to break seed dormancy of many species. Moreover, the passage of fire makes it more difficult to remove these perennials with an angady, because they are less easily identifiable and accessible after burning. The best solution is to wait for vegetation regrowth (some weeks after burning or at the beginning of the rainy season) to apply a total herbicide (glyphosate at 1,800 g/ha). After direct seeding (no tillage, but without vegetation cover because it burned), the control of annual weeds that can quickly re-colonize these plots is done by applying pre-emergent (if weed flora is known and exerts great pressure) or post-emergent herbicide (decision made on a case by case basis, depending on the appearance of annual plants).

Examples of low residues, without perennial weeds
In a plot that produced traditional rice, at a low yield (1 ton/ha), and with a weed flora dominated by annual broadleaf weeds, it is possible to direct seed maize (preferably associated with a legume in order to increase biomass production) after a single treatment with 2,4-D a few days before seeding (at least 8 days before seeding a legume) to eliminate regrowth of young broadleaf weeds. Afterwards, weed control may require a new treatment with 2,4-D applied on broadleaf weeds (unless the maize is associated with a legume) and grass removal.

Very degraded plots, operated mechanically
In the particular case of large and unlevelled and bumpy plots that you want to use under mechanized agriculture, it is necessary to till, after herbicide treatment, in order to level them to allow mechanized direct seeding in the following years.

Example of low residues, with perennial weeds
In Lake Alaotra, in rice fields with poor water control, Cynodon dactylon frequently invades the areas that are not flooded long enough. The best technique is to eradicate it by using glyphosate (1,800 g/ha) during the vegetative season, preferably in the previous rainy season, or otherwise after vegetation regrowth at the beginning of the rainy season.
Establishment of direct seeding cropping systems
Selection of the operational sequences

On plots with low biomass and without perennial weeds (either because they were not present, or because they were removed by the previous operation), the choice of the operational sequence is made mainly according to the risk of soil sealing or induration.

Tilling sealed or indurated soils (in year «zero»)
Sealed soils are generally loamy, sandy loam or sandy-clay soils that can be found towards the bottom of the toposequence: exposed soils in the plain or baiboho, ferruginous tropical soils, etc. They represent most of the rice field soils (with the exception of some poorly evolved organic soils). Crop residues are generally scarce; a large vegetation cover on the soil allows suppression of this sealing phenomenon. On these sealed soils (or in the case of surface induration), tillage is necessary after perennial weed control, in order to break the suffocating crusted surface.

On heavy soils, which are difficult to work, tillage must be done preferably at the end of the rainy season, which makes it possible to seed early without having to wait for enough rain to till at the beginning of the agricultural year. On light soils, which are easier to work, tillage can be done during the dry season, once again in order to be ready for an early seeding after the first relevant rains (after a possible application of herbicide at low-dose on young plants that may regrow during the dry season).

In all cases, on sealed soils that must be tilled before seeding, it is important to avoid very fine crumbling and not to pulverise them. By destroying the soil structure excessively, you will create sealing crusts or surface induration under the action of rain. Tillage should be coarse: it should consist of tillage and coarse crumbling or passage with toothed tools, «Canadian» style, that are more than sufficient and preferable than other practices. This kind of tillage helps to control annual weeds before seeding.

For the establishment of an off-season crop or a cover plant on a sealed soil, it is possible to till only the seed hole.

Mulching these soils after tillage, if biomass is available nearby, is particularly interesting because it strongly reduces soil sealing or induration risks.

The options on non-sealed soils
On non-sealed soils (tanety soils and organic soils poorly developed in rice fields), tillage is not essential. On plots that had perennial weeds, the operations performed to control them generally have greatly reduced the amount (when peeling off with an angady) or eliminated all annual weeds (if using herbicides). Only resprouts (when existent) need to be removed before seeding. In plots that did not have perennial weeds, an easy and inexpensive control of annual weeds can be done by herbicide use before seeding, or otherwise by tillage.

During year “zero” of direct seeding preparation, tillage followed by crumbling is often the simplest solution, requiring no herbicide while being well controlled by farmers. It is also possible (and recommended) to simply control annual weeds, similarly to the plots already installed under DMC, which has the advantage of reducing working time and to get used to direct seeding practices.

On the plots already under DMC (as a result of an «accident» that did not allow maintaining sufficient biomass on the soil), tillage should be avoided as much as possible because it rapidly loses the benefits obtained during several years under DMC. Thus, plot preparation is limited to the control of annual plants in vegetative growth, which can be done by:
Establishment of direct seeding cropping systems
Selection of the operational sequences

- application of herbicides, at low doses, a few days before seeding. A mixture of glyphosate (360-540 g/ha) and 2,4-D (360-720 g/ha), used on the infested parts of plots is sufficient to fully control annual flora vegetative growth without disturbing the soil. This method is also the fastest, especially if weed re-sprouts are numerous, but it requires herbicide use (cost, knowledge, product and spraying equipment availability problem);
- mowing, passing a knife roller or rotary shredder if the weeds are at an advanced stage of development (these practices are not very efficient on seedlings);
- hand-pulling weed seedlings when they are few;
- as a last alternative, if none of these methods are practicable, light and localized weeding is faster than hand-pulling but has the major disadvantage of disturbing the soil.

The «recharge» of biomass by importing straw is highly recommended (when such biomass is available nearby), to cover the soil and limit annual weed regrowth.

**Mulch input**

On direct seeded plots with low biomass, or after tillage, straw supply reduces erosion and allows the control of most weeds, as long as the mulch is sufficiently thick. Mulching must be done preferably before seeding, but can also be done after crop emergence (which is more delicate, longer and less efficient).

The type of straw used determines mulch degradation rate and therefore how long it will maintain itself (for weed control), and the risks of nitrogen blockage (for cereal crops):
- straw with high C/N ratio (like sorghum or maize stalks) decompose slowly and thus stay longer, but induces a high nitrogen blockage risk at the beginning of the cycle;
- legume leaves (low C/N ratio) decompose very quickly which can cause problems for weed control, but quickly return nitrogen to crops;
- grass leaves and legume stalks decompose at an intermediate rate.

This technique is extremely simple and efficient, but it has two major constraints:
- it can only be done if the biomass is available nearby and in significant amounts;
- it requires significant working time (even greater when biomass has to be transported over long distances), even if this work can be done during the dry season.

Therefore, mulching cannot be recommended in areas where straw is scarce, such as areas where dairy farming is an important source of income and/or in areas where land pressure is high.

In all cases, biomass production along plot boundaries (anti-erosion bands or living hedges, with perennial or semi-perennial plants such as Bana grass or cajanus that will be regularly mowed) or in neighbouring plots (improved fallows) can help to quickly and easily import high biomass into cultivated plots, and thus ensure a rapid entry into direct seeding.
Establishment of direct seeding cropping systems
Selection of the operational sequences

2.3. Control of vegetation cover through high biomass

Efficient DMC practices enable (and work well thanks to) high biomass production and its restitution to the soil. To start DMC systems, high biomass is obtained after a year «zero» of DMC preparation by crop association (or succession) with annual or perennial cover plants with high biomass production. It is also possible to start DMC systems directly in perennial fallows or after intensive cropping with high biomass production. Once installed, DMC systems are maintained by keeping high biomass production, largely returned to the soil.

This high biomass available on the plot can directly prepare the vegetation cover for direct seeding under good conditions, on soils that often are well-structured and non-sealed.

The choice of vegetation cover control method (mechanical or by herbicide use) is based on:

- the species (and sometimes even varieties) on which depends the facility of mechanical and chemical control, and consequently the possibilities and the comparative advantage of using one control method rather than another;
- their vegetative growth that influences the possibilities of use and the effectiveness of herbicides and mechanical control, and therefore their comparative interest;
- the available means: access to herbicides and cost, availability and cost of work force, access to equipments;
- the type of vegetation cover that is desired: dead or living mulch (difficult to manage without herbicide);
- the crops that we want to install in the case of living mulch; and
- climate: duration of the dry season that determines the period of plant vegetative activity; eventual frost, which weakens (and can even kill) plants.

If herbicides are used to prepare the vegetation cover, the doses to be used depend on:

- the species to control;
- their vegetative stage;
- application conditions;
- the desired cover type (dead or living).

<table>
<thead>
<tr>
<th>Crops to be established</th>
<th>Herbicide use</th>
<th>Type of mulch (dead or living)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available resources and cost</td>
<td>Vegetation cover preparation method</td>
<td>Cover plant: Species Vegetative stage</td>
</tr>
<tr>
<td>Mechanical control</td>
<td>Climate: Frost Dry season</td>
<td></td>
</tr>
</tbody>
</table>
Control of fallow plots with perennial plants (not burned)

Spontaneous plants often perform many functions in the ecosystem performed by their selected «cousins» and can be often used as vegetation cover. They have the advantage of already being present, but sometimes are disadvantageous in terms of management. Under perennial fallow, soils are often well structured thanks to perennial plants’ root systems and to their soil coverage. Moreover, the available biomass is often important (if it has not been burned). Crop direct seeding is possible from the first year of intervention, without the need of a year «zero» of preparation. The operational sequence to be adopted depends primarily on the species to master. In many cases, the most efficient way to control these perennial plants is the application of total herbicides, at relatively high doses.

However, several scenarios occur:

Perennial broadleaf and erect perennial grasses (mainly on tanety)

These plants can only be used to prepare a dead mulch. They can be controlled mechanically without requiring too much work when they are scarce, which is usually the case of perennial broadleaf with taproots (Sida sp., Urena lobata, etc.) that can be killed by a single stab with an angady at the base. Annual plants that can coexist with these perennials can be controlled simply by mowing or by passing a knife roller after peeling off perennials.

2,4-D amine at a dose of 1,080 g/ha also helps to control most perennial broadleaf weeds (as well as annuals) at a very low cost and with little work. For broadleaf shrubs (like Lantana camara, very widespread in Madagascar, and Chromolaena odorata, very common in Africa and Asia), the best solution is to mow them, wait for their regrowth (about 3 weeks, time needed for some stems to develop some broad leaves) and then to apply 2,4-D (at 1,080-1,440 g/ha). Erect grasses (Aristida sp., Hyparrhenia sp., Andropogon sp., Cenchrus sp.; Imperata cylindrica, Brachiaria sp., etc.) can also be controlled by peeling them off (below the soil) at root level with an angady. However, they are often very numerous and the work required is very substantial. In this case the use of herbicides is highly recommended. These plants are controlled by the application of glyphosate at a dose of 1,800-2,160 g/ha if the plants are old. It is possible to reduce the dose by mowing the existing vegetation and by applying glyphosate at a dose of 1,080 g/ha on resprouts aged 2 - 3 weeks (which has the disadvantage of delaying seeding).

A species such as Imperata cylindrica, which is difficult to control because it is very rizomaticous, is better controlled if its biomass is left in place and it is used to seed a twining plant that covers the ground quickly (such as mucuna or Vigna spp.).

On a mix of perennial broadleaf and perennial grass weeds, the association of glyphosate (1,080 g/ha) and 2,4-D (720-1,080 g/ha) may be proposed. The dose of each herbicide varies according to the abundance of each type of perennial weed.

Examples of perennial weed control in fallow plots

In the highlands, the plots «invaded» by well-developed Cynodon dactylon allow high production of beans (or soybean) after a simple application of low-dose herbicide (720-900 g/ha of glyphosate) that allows controlling Bermuda grass without killing it. The living mulch is well-maintained and the system sustains. In the South West, fallows with well-developed Hyparrhenia sp. or Andropogon sp. allow high production of cotton under the DMC system after glyphosate treatment (at 1,800-2,160 g/ha, during vegetative growth).

Creeping or small perennial grasses

These types of grasses (such as Cynodon dactylon, present on tanety and exposed rice fields in all ecological zones, and small brachiaria or Panicum, Pennisetum clandestinum or Stenotaphrum secundatum in wet climate), are extremely difficult to control without using herbicide. In fact, tillage (even at the beginning of the dry season) is often insufficient to control them and sometimes can even facilitate their proliferation via rhizomes that were cut into pieces.
Establishment of direct seeding cropping systems
Selection of the operational sequences

These perennial grasses are often dominant and cover the soil very well. They can be used as vegetation cover after total (dead mulch) or partial (living mulch) control.

- **Creeping perennial grasses as dead mulch**
  
  To prepare a dead mulch these plants are killed by application of glyphosate at the dose of 1,800-2,160 g/ha. The ideal situation is to control them during their vegetative growth, at the end of the rainy season of the previous cycle, which allows increasing control effectiveness (especially because the plant must resist to dry season) and seeding early. If these perennial weeds have not been controlled in advance, you must wait for vegetative regrowth after the first rains (from 15 days to 3 weeks, approximately) to apply herbicide to plants during their vegetative growth stage. Seeding can be done once the effect of the herbicide has been observed. Besides the risk of poor control of perennials, this operational sequence has the disadvantage of delaying seeding. In order to partly address this problem, it may be possible to seed directly, immediately after herbicide application. Thus, there is the risk of perennial regrowth locally if some parts were poorly treated or forgotten.

- **Creeping perennial grasses as living mulch**
  
  These creeping perennials that fully protect the soil and control the majority of weeds can be used to perform a living mulch. This requires the use of herbicides to control them temporarily and to allow crop establishment and growth, without killing them so that they produce high biomass after crop harvest. *Cynodon dactylon* is very suitable for this practice, allowing the sustainable production of the legume by providing permanent soil cover.

  The control of these creeping perennial plants used as living mulch is done by applying a reduced dose of herbicide: glyphosate (720-900 g/ha according to its vigour and its stage of development) or 1/2 to 2/3 of the recommended doses of “fop” group graminicides (when they are available). Homogeneous application of herbicide must be well-mastered in order to avoid killing the plant in overdosed areas, and poor control in under dosed areas.

**Control of perennial cover plants**

Control of established perennial cover plants

Many species used as perennial cover plants belong to the same genus and sometimes to the same species as spontaneous perennials. Cover crops were selected to maximize agronomic interests (biomass production as priority, the selection being made initially by farmers) and to facilitate their management. Perennials with rhizomes and stolons are difficult to control mechanically, unlike annual plants that do not regrow if mowed or rolled after heading.

Thus, one can use as vegetation cover:

- different varieties of brachiaria (especially *B. ruziziensis*, *B. brizantha*, *B. decumbens*, *B. humidicola* and *B. mutica*) selected from plants of Eastern and Southern Africa in order to improve forage production and quality, and which were distributed all over the world as forage;
Establishment of direct seeding cropping systems
Selection of the operational sequences

- Tifton varieties (Tifton 68, 78 or 85 are the most famous), a hybrid of *Cynodon dactylon*, selected for their higher production and particularly for their better forage quality;
- *Cenchrus ciliaris* similar to *Cenchrus echinatus*, but with better forage quality and especially easier to use because of its non-spiny seeds;
- different *Pennisetum* sp., particularly those derived from *Pennisetum purpureum* (Elephant grass) and its hybrids (particularly *Pennisetum glaucum* such as Bana grass, and Capim elefante carajas), and *Pennisetum clandestinum* (Kikuyu grass);
- *Andropogon gayanus*, ryegrass, etc., and several legumes, as:
  - *Stylosanthes guianensis* cv CIAT 184, relatively resistant to anthracnose, a fungal disease that had practically eradicated this very interesting forage species in the 1970s;
  - *Desmodium* sp., *Centrosema* sp., etc.

Control of perennial grass cover
The total control of perennial grass cover (dead mulch) that produces high biomass is done in an optimum way from 3 to 6 weeks before the planned cultivation date. Control in advance has the following advantages:

- allows ensuring a proper control of these perennial plants;
- allows obtaining a compacted mulch, which facilitates seeding (which can be very delicate on a recently controlled high biomass);
- allows initiating the biomass decomposition process and in particular reducing the risk of nitrogen blockage which can be very damaging to crops, especially cereals grown on a grass mulch (initially, the bacteria involved in the decomposition and mineralization processes consume nitrogen, before releasing it in quantity);
- allows crops to emerge rapidly through the cover, which prevents etiolation of seedlings and fungus attack.

However, climate and vegetative cycles do not always allow preparing coverage during this optimum period. In climates with a dry season, it is often better to control vegetation cover at the end of the previous rainy season, during vegetative stage when the employed systemic herbicide is efficient. We simply need to make sure, before seeding, that perennial weed control was efficient, and that plots are clean (which is generally the case when the amount of biomass is high). If necessary, when weeds are present in small quantity we can remove them by hand-pulling, or if young plants are quite abundant by applying low doses of herbicides (540 g/ha of glyphosate and 360-720 g/ha of 2,4-D).
In these climates, if mulch has not been prepared in advance, you must wait for vegetation regrowth after the first rains, which delays seeding and increases the risk of nitrogen blockage in the beginning of the cropping cycle.

- **Cynodon dactylon cv Tifton**
  Tifton varieties are controlled in the same way as *Cynodon dactylon* found in fallow plots with perennials: 1,800 to 2,160 g/ha of glyphosate for a dead mulch, and 720-900 g/ha of glyphosate or 1/2 to 2/3 of the recommended doses “fop” group graminicides for a living mulch. Tifton 85 is particularly difficult to control without herbicide due to its very large rhizomes and stolons with fast development. The control of Tifton 68 (no rhizomes) without herbicide remains very difficult and demanding in terms of the amount of labour.

- **Brachiaria sp.**
The different species of brachiaria are used to produce a significant vegetation cover, used under DMC to produce dead mulches. They do not allow cultivation on living mulches. Brachiaria control method varies according to the species: *Brachiaria ruziziensis* is the easiest to control, preferably by herbicide or by mechanical action. Chemically, it is fully controlled with 1,080 g/ha of glyphosate while the other species (*B. brizantha, B. decumbens, B. mutica and especially B. humidicola*) are more resistant and require from 1,800 to 2,160 g/ha of glyphosate to obtain an efficient control. Mechanically, its tufted habit and less powerful roots allow taking into consideration a control by peeling off with an angady whenever necessary (no access to herbicides or very high cost, exceeded control period and therefore risk of low effectiveness of weed control, etc.). *B. Brizantha* or *B. decumbens* can have a tufted habit that enables peeling off with an angady but at a very high work cost (and decreased performance of DMC systems because of soil disturbance). *B. humidicola*, which has a very strong root system and many stolons and rhizomes is difficult (but possible) to control mechanically.

Finally, *B. ruziziensis* is the most frost sensitive species. It can be killed by frost below -3°C, in which case it is not necessary to treat it with herbicide: seeding can be carried out directly without special preparation. In the case of a more moderate frost (-1 to -2°C) it needs a low herbicide dose (360 to 720 g/ha depending on its state). *B. brizantha and especially B. decumbens* are much more resistant to frost.

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*Pennisetum clandestinum* (kikuyu grass)  
Kikuyu is a plant used mainly as living mulch for legume cultivation (beans, soybean). Its establishment by cuttings is relatively long, that is why its use as dead mulch is not very interesting. Its control before seeding is done by simple mowing. After seeding, it is controlled by using a selective herbicide (propaquizafop at a dose of 50 g/ha or fluazifop-P-butyl at 62.5 g/ha) or glyphosate at 720 g/ha or less, depending on its vigour and on the possibility of controlling the living mulch during cultivation, by applying selective herbicides. In the highlands, kikuyu grass during the first year after establishment is generally underdeveloped and legume cultivation can be done directly without special treatment before seeding.

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### Avoid seed production

Among all these perennial grasses, kikuyu grass is the only one that can be controlled chemically (in legume cultivation) and that has a slow establishment, which does not represent a problem in case of restarting by seeds. All the other perennial grasses are difficult to control chemically (especially in cereal cultivation) and it is important to avoid producing seeds, so they will not «infect» the plots during the next cropping season. This can be achieved by mowing at flowering or by grazing them.
• *Lolium multiflorum* (Italian rye-grass)
Italian rye-grass is a plant with a particular cycle, which may be annual or biennial or even semi-perennial. A simple mowing generally does not allow controlling it. In rice fields, where it is generally used during the cold season (being demanding in terms of water, resistant to waterlogging and very resistant to frost), its control is carried out by using glyphosate at a dose of 1,080 g/ha.

<table>
<thead>
<tr>
<th>Cynodon dactylon cv Tifton</th>
<th>Dead mulch</th>
<th>Living mulch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glyphosate at 1,800–2,160 g/ha</td>
<td>Glyphosate at 720-900 g/ha or 1/2-2/3 of the recommended dose of “fop” group graminicides</td>
</tr>
<tr>
<td>Brachiaria ruziensiensis</td>
<td>Glyphosate at 1,800–2,160 g/ha or peeling off with an angady</td>
<td>Difficult to control</td>
</tr>
<tr>
<td>Brachiaria brizantha, B. decumbens, B. humidicola, B. mutica</td>
<td>Glyphosate at 1,800 – 2,160 g/ha</td>
<td>Difficult to control</td>
</tr>
<tr>
<td>Pennisetum clandestinum (Kikuyu)</td>
<td>Not interesting</td>
<td>Mowing (then propaquizafop or fluazifop-P-butyl) or glyphosate at 720 g/ha</td>
</tr>
<tr>
<td><em>Lolium multiflorum</em> (Rye-grass)</td>
<td>Glyphosate at 1,080 g/ha</td>
<td>Difficult to control</td>
</tr>
</tbody>
</table>

**Control of a perennial legume cover crop**
Thanks to the rapid decomposition of legume leaves with high nitrogen content, the risk of «nitrogen hunger» is limited. The control of vegetation cover can be made just before seeding, especially in the case of a creeping species, where biomass is quickly compacted.

Perennial creeping legumes (*Arachis pintoi* and *A. repens, desmodium* and clover) are used only for the preparation of living mulches. Their slow establishment, mostly by cuttings, makes them uninteresting to use in dead mulches.

Perennial erect legumes (cajanus, crotalaria, stylosanthes) are used in dead mulches (which can reseed naturally, as in the case of stylosanthes).

• *Arachis pintoi* or *Arachis repens*
Cover plants control is done one or two weeks before the estimated seeding date. An excessively early control is difficult because plant vegetative activity is low (and therefore, the systemic herbicide is less effective) and not very interesting because coverage control is made only for a limited time, and should be used at its best. Their control is delicate and requires experience. The herbicide dose to be used is from 360 to 1,080 g/ha of glyphosate, according to plant vegetative stage. The low dose used when they have experienced frost or a long dry season must be increased if the cover plant is rather well developed and in full activity.

The difficulty lies with dose adjustment and application regularity, so that the applied dose is:
- not too high, because it could kill plants and produce low biomass for the following season (however, it does not require a new establishment of *Arachis* because it will naturally restart, but slowly, thanks to the seeds that remained in the soil);
- nor too low, because it would cause the risk of excessively rapid regrowth of cover plants and thus competition with the crop. In this case a selective herbicide must be applied on the crop, such as triclopyr at a dose of 360-480 g/ha.

*Control of Arachis pintoi on maize seeding rows*
Herbicide application is carried out during the establishment of high density crops, such as rice. It can be done in spaced rows, where crops, such as maize, will be grown. The amount of applied herbicide is greatly reduced and therefore its cost, and management is easier.

When available, we can also use a localized or a general application of diquat or paraquat in crop rows, at a low-dose (300 g/ha), or a saline solution (KCl 25% + vinegar) for a sufficient control of **Arachis** during the first 30 days of the cropping cycle.

Finally, for the establishment of a maize crop on a living mulch of **Arachis** sp., it is also possible to use atrazine at a dose of 1,000-1,250 g/ha.

- **Desmodium uncinatum**
  At altitude (> 1,500 m), **Desmodium uncinatum** can be controlled naturally by frost, thus, no treatment is required before seeding.
  In the absence of frost, **Desmodium** can be mowed once (and possibly used for animal feed), which is generally sufficient to control it during the time that the crop needs to establish itself. Controlling with glyphosate at a low dose (180 g/ha) is also possible for those who do not have the required work force for mowing and/or who do not wish to feed animals.

- **Trifolium repens**
  Like **Desmodium**, white clover can be sufficiently controlled by frost in altitude, or by a simple mowing. It can also be controlled chemically by using 2,4-D (1,060 g/ha).
  In rice fields, it can also be controlled by flood. Finally, a supply of nitrogen fertilizer (urea) may also be sufficient to control it during the time needed for the crop (preferably cereal) to develop sufficiently to no longer fear its competition.

- **Cajanus cajan or crotalaria sp.**
  Semi-perennial, shrubby and ligneous plants, cajanus and crotalaria are easily controlled by mowing at ground level (by using an angady or by manual cutting). Cut biomass is left on the plot.
  Precaution to be taken: once mowed at the base, ligneous stems can be sharp. It is recommended to wear shoes for working in these fields.
  It is also possible to control crotalaria by passing a knife roller, heavy enough to cut the stems that are still very little lignified.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Dead mulch</th>
<th>Living mulch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arachis pintoï or A. repens</strong></td>
<td>Not interesting</td>
<td>Glyphosate at 360-1,080 g/ha</td>
</tr>
<tr>
<td><strong>Desmodium uncinatum</strong></td>
<td>Not interesting</td>
<td>Frost, mowing or 2,4-D at 1,060 g/ha</td>
</tr>
<tr>
<td><strong>Trifolium repens</strong></td>
<td>Not interesting</td>
<td>Frost, mowing or 2,4-D at 1,060 g/ha</td>
</tr>
<tr>
<td><strong>Cajanus or crotalaria</strong></td>
<td>Peeling off with an angady</td>
<td>Not possible</td>
</tr>
</tbody>
</table>
• *Stylosanthes guianensis*

If you wish to use stylosanthes as a dead mulch, total control should be done at the end of the dry season, from two to ten weeks before the estimated seeding date. The higher the biomass above ground, the sooner you should control it. Seeding into a very high biomass can be difficult, so it would be easier if this biomass is compacted.

**Manual weed control**

An advantage of *Stylosanthes guianensis* for DMC systems in small family farms is that, despite being a perennial, it can be completely controlled by a single mowing at ground level. In manual cultivation, it is sufficient to cut it with an *angady* stroke, or in mechanized cultivation, by passing a rotary shredder or a scythe hammer. Then, stylosanthes plants are killed to make a dead mulch. However, the system can be easily continued by simply leaving stylosanthes to produce seeds before cutting it, allowing the cover plant to re-establish naturally.

In the case of a «medium» biomass (5 to 10 ton of dry matter/ha), the mowed stylosanthes may be simply left on the ground without interfering with the mowing process.

In the case of high biomass (12-20 ton/ha), the thickness of the above-ground biomass makes it difficult to reach the plant base to cut it manually. However, several ligneous stylosanthes stems make up an easy to handle coverage. The possibility to wrap it allows accessing the plant base and to cut it.

By pulling or pushing biomass with the handle of an *angady* we can easily wrap it.
Establishment of direct seeding cropping systems
Selection of the operational sequences

When the roll is considered to be too heavy and difficult to handle, the vegetation cover is cut in bands with an angady. The formed bands are about ten meters long.

If necessary, the soil is levelled under the vegetation cover, for example in the case of the development of termite mounds.

The roll is then unwrapped and the vegetation cover is put back in place to cover the ground. The process continues by making a new roll and so on.

The vegetation cover is flattened naturally and allows seeding under excellent conditions about a month later, without further treatment.

This biomass often allows weed control over two cropping seasons (except under a hot and humid tropical environment throughout the year).

Mechanical and chemical control
For large plots, manual control is very demanding in terms of time. Mechanical and chemical control is preferable. This control is done by rolling (or trampling) stylosanthes when the biomass is considered sufficient. When it recovers, we can apply either an herbicide mixture (540–1,080 g/ha of glyphosate + 1,080 g/ha of 2,4-D), or a 25% KCl solution with vinegar (3 litres of vinegar per 100 litres of solution). Therefore, the dose of KCl to provide per hectare depends on the amount of solution used (25 kg/ha for a solution of 100 l/ha, but 50 kg/ha for a solution of 200 l/ha. The concentration of the product, and thus the generated osmotic pressure, being more important than the dose).
Control of plant covers based on off-season crops or annual cover crops at end of the cycle

One of the aims of DMC systems is to optimize biomass production and to have a significant vegetation cover when establishing the main crop. Besides perennial cover crops, we can:

• use annual cover crops which are able to grow during the dry and/or cold season. These plants, established in relay (seeded into the crop at the end of the cycle) or in succession (seeded after crop harvest) in the main crops produce high biomass during the off-season. Their cycle is generally «adjusted» to provide maximum biomass (after flowering) just before seeding the next crop;

• install off-season crops that will finish their cycle just before the period of cultivation of the main crop. Besides producing a profitable crop, when possible these off-season crops allow «sustaining» the DMC system by the regular input of biomass. Generally, perennials are absent in these situations, having been controlled before the establishment of annual cover crops (the few plants that survived can be easily stripped with an *angady*). In addition, these annual plants have generally eliminated annual weeds from the plot (or perennials, in some cases such as vetch on cynodon), by shading and/or allelopathy effect. All the following annual plants are easily controlled: grasses such as oats, wheat or barley; legumes such as vetch, vigna, dolichos bean or peas; or cruciferous such as forage radish. They all die naturally after producing seeds. Plot preparation consists only in verifying that weeds will not develop (if weeds develop, the application of an herbicide at a low dose is required: 540 g/ha of glyphosate for grasses, 720 g/ha of 2,4-D for legumes) and flattening straw on the ground, which can also be done during harvest.

Control of plant cover composed by abundant crop residues and annual cover crops that finished their cycle

When climate and water regime do not allow off-season cropping, biomass production increase required to «supply» DMC systems is obtained by associating crops with cover plants. However, these crops and cover plants finish their cycle several months before seeding the next crop. It needs no special control because they are already dead. However, during the period without any established crop or cover plant, weeds can grow. They become even more abundant when the biomass on the ground is not significant and when the period without cultivation is longer. Thus, plot preparation consists only in controlling these weeds that can develop. These weeds are usually annual weeds that can be controlled:

• by mechanical mowing (if they are scarce and tall, but did not complete their cycle, it is not necessary to treat them), passing a knife roller (or a tiller with cage wheels) or a rotary shredder to control the vegetation that is still alive (leaving the straw on the ground);

• chemically by the application of an herbicide at a low-dose (360-720 g/ha of 2,4-D on broadleaf weeds, 360-540 g/ha of glyphosate on grasses, optionally as a mixture) if they are abundant and in the vegetative stage.

In plots with a large amount of crop residues, which is rare, but where perennials have not been eliminated (due to failure of a previous treatment), the only solution is to mow and remove biomass in order to be able to apply a total herbicide on perennial plants (the direct application of herbicide is not possible because biomass can capture the herbicide and protect the perennials below). If perennials are dispersed in ensembles, you simply have to carry out this operation locally on these ensembles.
The control of vegetation covers composed of different species

When the vegetation cover is composed of different species, the control is carried out as follows:

- Mechanically, by mowing, passing a knife roller or a rotary shredder if all the species used in the mixture can be controlled this way (mixture of annual plants like oat + vetch + fodder radish + lupine, for example);
- Chemically, by applying herbicide at the dose needed to control the most resistant species, and eventually mixing herbicides to control a mixture of grasses and legumes (mixture of glyphosate and 2,4-D to control a mixture of brachiaria and cajanus, for example).

In the case of a mixture of cover plants that include perennial species that we wish to control without using herbicide, it is possible to strip with an *angady*, but at a very significant cost.

2.4. Synthesis on plot preparation

As tillage has a very negative impact on the «soil» ecosystem it should be avoided whenever possible. It is only useful in year «zero» of direct seeding preparation on plots with low biomass availability, particularly on sealed soils.

The year «zero» of plot preparation must absolutely eliminate all the perennial plants that we do not wish to keep as living mulch.

<table>
<thead>
<tr>
<th>Working time needed to control vegetation cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>The application of herbicide with a backpack sprayer takes 4-6 working days per hectare.</td>
</tr>
<tr>
<td>The passage of a knife roller pulled by zebus takes on average 3-5 days/ha per pair.</td>
</tr>
<tr>
<td>Peeling off with an <em>angady</em> takes much longer, more than 150 days/ha in cases of perennial rhizomatous plants, which are abundant.</td>
</tr>
<tr>
<td>Manual preparation of stylosanthes cover with high biomass takes 100-120 days/ha and requires the mobilization of teams with 4 to 5 people, who work together.</td>
</tr>
</tbody>
</table>

According to the available resources and the species present, the control of perennial plants can be done by:

- Simply peeling off with an *angady*, which has the advantage of being done without specific equipment or inputs, during the dry season (when the amount of other work is relatively low), but it causes soil disturbance and it is difficult to perform on plants with stolons or rhizomes and generates considerable work;
- By repeated tillage (technically well mastered by farmers), without chemical inputs, but at a high cost due to the very significant amount of work (especially when it is done manually) and produces erosion and soil disturbance;
- By herbicide treatment, which requires good technical mastery of these products and can only be done if they are accessible and if we have the necessary equipment. However, this practice permits excellent control of all undesired plants, in a short time, without soil disturbance or erosion. Thereafter, for the establishment of crops under DMC, plot preparation consists only in controlling the vegetation cover (annual or perennial plants), which can be done (according to the species to control and available resources) by:
  - Herbicide treatment, with the same advantages and constraints as when used to control perennials during year «zero», but it also allows temporary control of the living mulches and is interesting, compared to other practices, to protect the vegetation cover from being washed away by the rain (especially on steep slopes). However, this practice can be difficult to implement with a simple sprayer in the case of a plot with very high biomass (but it is not a problem in mechanized agriculture) and must sometimes be done at a specific period (flexible application, variable according to species);
  - Peeling off with an *angady*, with the same advantages and disadvantages as when used to control perennial weeds. However, it is not possible to prepare living mulches this way if the cover plant cannot be partially controlled;
  - Mowing, rolling or rotary cutting a dead mulch with annual plants. These very simple techniques require no special knowledge (only about plants). Hand mowing is hard work, but can be done with very simple tools. A knife roller, inexpensive and simple to manufacture, significantly reduces working time. Rotary cutting is very fast but requires a much higher investment.
Herbicides for plot treatment

For the treatment of no-tillage plots, two systemic herbicides are of particular interest:
- glyphosate, which controls most of the grasses and perennial sedges (and some broadleaf weeds) at a dose of 1,800 g of active ingredient/ha;
- 2,4-D amine which controls most broadleaf weeds at a dose of 1,080 g of active ingredient/ha.

They control annual plants at lower doses (360 - 540 g of glyphosate/ha, 360-720 g of 2,4-D/ha).

According to the type of plants to control and their stage of growth, both products can be used in a mixture at varying doses, by:
- favouring 2,4-D which is very cheap on broadleaf weeds and glyphosate on grasses;
- reducing doses on seedlings during the vegetative stage and increasing doses to control older plants, with slow vegetative growth.

2.5. Some mistakes to avoid when preparing plots

Plot preparation is an important step that affects the rest of the operational sequence. It is important that it succeeds and to avoid mistakes that create difficulties in plot management, we must be very careful to avoid in particular:
- poor control of perennials during year «zero», which may be related to poor application of herbicide or bad choice of practices (tilling plants with rhizomes, for example), which causes crop management and direct seeding difficulties during the following years;
- tillage when it is not necessary in year «zero» and in the following years on established DMC systems because it could cause difficulties;
- the treatment of an insufficient coverage when you do not have the means to ensure good weed control thereafter (better to concentrate biomass);
- the control of a low biomass coverage carried out too early and especially when biomass is based on fast-decomposing legumes, which may result in poor weed control;
- the control of a very high biomass coverage carried out too late, which can cause difficulties when seeding into a vegetation cover that is not compacted enough.
3. Seeding

Seeding is a key stage of the operational sequence, which fixes the conditions of crop establishment and growth, and weed control. It is during seeding that the adjustment of a large number of parameters is done. It allows the optimization of the plant population and their production of grains, fibres and/or tubers, and total biomass.

Therefore, the establishment of the plant population is carried out in order to meet two objectives:

• to manage competition with the main crop (in the case of crop association);
• to allow good production of associated plants or plants in succession.

This double objective should be achieved with the resources available (work force, equipment, inputs), taking into account the constraints at the farm level. For this reason, various seeding technical parameters can and should be precisely adjusted.

The optimum seeding methods are largely dependent on the agronomic situation or unit that determine the period of possible production.

For a given agronomic unit (climate x water regime x fertility), the seeding method (date, technique, rate, depth, spatial arrangement and fertilization of the different plants) that allows managing the competition between plants, depends primarily on specific and varietal characteristics of cultivated and associated plants. These plants are selected (when selecting systems, cf. Volume II. Chapter 1.) for their ability to adapt to this agronomic unit and for their relative competitiveness for light (related to the cycle, initial vigour and habit), water and nutrients (mainly related to their root system).

The optimum technical parameters of seeding for a given cropping system on a given agronomic unit, are considered as an ensemble, with many interactions between the different parameters. However, an optimum plant density can be determined in advance, with several seeding parameters. These parameters, for an optimum plant density, are presented in detail in the technical data sheets per system and per zone (cf. Volume V), for each situation.

However, in practice, seeding is generally the result of a compromise that allows being as close as possible to the optimum level of these parameters, with the resources available at the farm level (work force, equipment, etc.). Hazards mean that these optimum levels cannot always be obtained in all seeding parameters. When a parameter cannot be achieved in an optimum way, it is then indispensable to adjust the other seeding parameters in order to optimize plant population according to the real situation in the field.

Therefore, crop association management requires forward planning (when designing systems and operational sequences) and responsiveness (during establishment on the field).

Some seeding parameters are fundamental and are strongly influenced by external factors (climate, soil fertility, etc.). They concern primarily the main crop, for which parameters are prioritized to the optimum. The seeding date and rate of the main crop (which determine plant density) are particularly important to ensure good production. Their performance under optimum conditions is a major objective to reach.
Other seeding parameters, related to associated plants (such as seeding date, method, rate, seeding depth or varieties), plant spatial arrangement or fertilization, are more flexible and can be adjusted easily. They are considered in a complex ensemble and give flexibility to obtain an optimal plant density, once parameters for the main crop are fixed and effectively carried out, in real situations (of weather conditions, available resources, main crop real seeding date, etc.).

Thus, determining optimum parameters is done taking everything into account, identifying first those of the main crop. For the main crop, if necessary, these parameters can be adjusted before seeding in order to facilitate the establishment of associated plants (in particular spatial arrangement, as in the case of seeding in double rows).

Seeding parameters of associated plants are then determined. However, they must be adjusted after the main crop seeding in order to adapt to the existing conditions of the plot under cultivation.

### Management principles of plant population

Priority is given to the main crop. Once the conditions for its success are ensured, associated plants are established in order to develop where and when space is available, without creating competition with the main crop. Population management is done through a time gap (seeding dates) and/or space gap (seeding rate, space arrangement) between plants and by regulating their growth rate (seeding depth, localized fertilizer application, establishment by cuttings or seeds at seeding time, mowing or herbicide application after seeding). As for weeds, we try to ensure that the associated plants do not suffer from competition from the main crop during the first 30-45 days of the cycle. From the moment that the crop has completely covered the soil, the associated species are controlled naturally and efficiently by shading. However, we must ensure that associated plants are placed in conditions which permit good biomass production, otherwise their value is limited.

### Selection of operational sequence: adjustment of seeding parameters

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<th>Task</th>
<th>Page</th>
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<td>Determine technical parameters in order to ensure main crop establishment in optimal conditions</td>
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<td></td>
<td>Main crop optimum seeding date</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Main crop optimum seeding rate</td>
<td>47</td>
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<tr>
<td></td>
<td>Crop seeding method adapted to the resources</td>
<td>48</td>
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<td></td>
<td>Seeding depth adapted to the main crop</td>
<td>49</td>
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<td>49</td>
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<tr>
<td>2</td>
<td>Determine technical parameters in order to ensure the establishment of cover plants in crop association or relay cropping</td>
<td></td>
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<tr>
<td></td>
<td>Optimum seeding date of associated plants</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Optimum seeding date of associated plants and plant spatial arrangement</td>
<td>54</td>
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<td></td>
<td>Seeding method or establishment of associated plants</td>
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<td></td>
<td>Varieties of associated plants adapted to the system</td>
<td>56</td>
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<td></td>
<td>of adapted associated plants</td>
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<td></td>
<td>Localized fertilizer application at seeding</td>
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<td>3</td>
<td>Carrying out seeding</td>
<td>58</td>
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Establishment of direct seeding cropping systems
Selection of the operational sequences

3.1. Ensure the main crop establishment and its growth conditions

Main crop seeding date

Optimum seeding date
The main crop seeding date has a strong influence on the system’s performance throughout the cycle. The optimum seeding date is determined mainly by the rains and/or the plot water regime. Plot preparation must be done as soon as possible in order to allow seeding after the first useful rains.
The main crop seeding date particularly influences the amount of biomass produced by the system and therefore its performance and rapidity of conversion from a conventional system into DMC.

A major advantage of direct seeding mulch-based practices is that they allow an early preparation of plots, which makes it possible to seed after the first useful rains. DMC systems also allow dry seeding at the end of the dry season, when the rains are starting; the risk of low germination after the first rains (which would not allow the seedlings to survive if the rains do not continue), important on bare soils, is strongly limited by the mulch that intercepts the water of the first rains. Seeds, placed under the straw are only wet when the mulch has accumulated more than 10 to 20 mm of water.
Thanks to good infiltration, the soil has a water reserve that allows plants to withstand dry periods, especially as evaporation is reduced by the vegetation cover.
Thus, direct seeding offers greater flexibility than conventional systems, and facilitates early seeding, which is a major advantage in agriculture.
In year «zero» of direct seeding preparation, which is often done after tillage, it is very important to seed early in order to allow fast entrance into these new methods. This requires performing soil preparation as soon as possible when necessary. An excessively late seeding in year «zero» can lead to insufficient biomass production in order to perform direct seeding under good conditions the following season, resulting particularly in plot preparation (should it be re-tilled or not?) and weed control difficulties. In addition, agronomic improvements related to direct seeding are not, or only poorly observed: slow improvement (or degradation) of soil structure, no weed control (they must be pulled out, which takes more time than weeding by tillage), etc. The transition from conventional to DMC systems becomes long and complicated.

The importance of early seeding
From an agronomic point of view, generally, early seeding is very beneficial. Respecting an early seeding date is particularly important because it allows:
• optimization of the cultivation period (crucial in long dry and/or cold season climates) and water use, and thus reduces climatic risks;
• establishing cover crops earlier and therefore under better conditions (some systems with intra-annual successions can even be impossible to manage without early seeding the main crop);
• maximizing total production;
• quickly obtaining good soil cover and thereby reducing erosion and weed pressure;
• reducing insect and disease pressure which multiplication cycles often begin along with the rain.

When seeding cannot be done early, agronomic constraints increase (increased pressure by weeds and pests, soil degradation by erosion of bare soils exposed to heavy rains at the beginning of the cycle, etc.). Climatic risks (lack of water to complete the crop cycle) also increase and production potential decreases rapidly (especially for photo-periodic varieties). When the climate is more problematic and pest and weed pressure is higher, the delay in seeding has more significant negative consequences.

In addition, seeding the main crop late makes association and/or succession management more difficult. It reduces the amount of biomass produced and, consequently, the performance of DMC systems. Thus, seeding must be done after the first useful rains, i.e., after 40 to 50 mm has fallen in a few days at the beginning of the rainy season. The soil water reserve allows withstanding two or three weeks without rain, which is common at the beginning of the cycle, when the rains are not yet «established».
In some very specific situations, seeding after the first useful rains is not the best agronomic option. **Very humid climate**

This is the case, in very humid environments in which it is best to adjust crop cycles (if this can be done by choice of varieties) in order to avoid arriving at flowering in a very cloudy period (to which rice is sensitive), or at maturity during the extremely rainy months (especially for sensitive crops such as soybeans).

**Risk of dry period**

This is also the case in environments, where there is the risk of a few weeks of rainfall «hole» during the rainy season, or bimodal type climate for which we must avoid the arrival at flowering, a very sensitive period, during a period of marked water deficit.

**Isolated plot under strong pressure from pests**

Additionally, when the pressure of certain pests such as birds or rats is strong (frequent in cleared areas), an isolated plot is more strongly affected than plots that attain maturity together on large areas. Thus, early seeding in an isolated manner loses its advantages.

### Effective seeding date

Seeding is a very demanding stage in terms of work (or in terms of equipment, in the case of mechanized agriculture). It is therefore difficult, at farm level, to accomplish all the seeding work in a very short period of time, especially if plot preparation could not be done in advance.

Thus, effectively seeding all the plots of the farm requires good organization and depends on:

- mobilization of resources at farm level at seeding (work force and equipment); and
- the time required to seed all the plots and therefore the method used (manual or mechanized, broadcast or in rows/holes), and the seeding rate.

In general, the means and methods of seeding must be adapted in order to allow seeding all the plots quickly, at an optimal seeding rate. However, when the means necessary for fast seeding cannot be mobilized, we must find a compromise between date, method and seeding rate compatible with the available resources, and that minimizes the loss of crop yield potential.

A major benefit of direct seeding practices is that they greatly reduce the work time needed for plot preparation and allow early seeding, on the entire farm. In the case of late seeding, production potential is lower and risks are higher, and input supply is not necessarily interesting nor even profitable. Production objectives, intensification level and other seeding parameters (spatial arrangement, density, depth and varieties) must be readjusted. When the delay is very significant, the cropping system itself cannot succeed and we should not hesitate to change it by using a less demanding, shorter cycle crop.

### Examples of crop seeding date

In the highlands, a very early establishment on *tanety* can be done using direct seeding practices, by dry seeding in October, before the first rains. It allows:

- establishing crops on *tanety* on time, without delaying seeding in rice fields (which, in general, are a priority);
- avoiding a risk of cold damage at flowering;
- reducing the risk of hail before harvest.
Establishment of direct seeding cropping systems  
Selection of the operational sequences

**Main crop seeding rate**

**Optimum seeding rate**

Together with the seeding date, the rate is a key factor that determines the main crop population and thereby its performance. This parameter should be adjusted according to the crop (species and variety), seed germination rate, weed pressure and production objectives, which are related to climatic restrictions (especially water) and fertility (soil fertility x fertilizer inputs). These production objectives can be reconsidered taking into account the effective seeding date (which influences climate risk and weed pressure), which can also lead on to reconsider fertilizer inputs.

The main crop seeding rate is based on the following objectives:

- to obtain quickly a good soil coverage (for light interception). This parameter depends on the species and varieties (especially their tillering capacity, for cereals) and on their supply;
- to allow plants to complete their life cycle under good conditions in terms of supply of water and nutrients. Therefore, the seeding rate adapts according to the most limiting factor. In case of missing one of them, a low rate allows the plants to complete their cycle thanks to soil reserves, while these reserves would be quickly depleted with a high seeding rate.

**Climate and water regime**

**Crop characteristics** (cycle, requirements)

**Plot preparation**

**Available resources**

**Crop characteristics** (habit, size, vigour)

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<table>
<thead>
<tr>
<th><strong>Cropping system</strong></th>
<th>Main crop and associated plants</th>
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<tr>
<td><strong>Production objectives</strong></td>
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</tr>
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<td><strong>Seeding parameters</strong></td>
<td>Seeding date, method, rate and depth of associated plants, Spatial arrangement, fertilization and varieties of crop and associated plants</td>
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<table>
<thead>
<tr>
<th><strong>Main crop optimum seeding date</strong></th>
<th><strong>Cropping system</strong></th>
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<tbody>
<tr>
<td><strong>Main crop effective seeding date</strong></td>
<td><strong>Production objectives</strong></td>
</tr>
<tr>
<td><strong>Main crop seeding rate and method</strong></td>
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**Seeding rate**

A high seeding rate allows the crop to cover the soil more quickly and to be more competitive with weeds. It can have a negative impact due to the rapid depletion of water resources and fertilizer elements when they are limiting factors. A low seeding rate allows avoiding this effect and ensuring that all plants have sufficient resources to complete their cycle. However, it limits crop production potential.

**Examples of seeding rate**

For maize seeded in the South west, in a semi-arid environment, on relatively poor soils and with a production target of 1-2 ton/ha, a density of 10,000 plants/ha is sufficient. For a production of 5-6 ton/ha on fertilized soils in Lake Alaotra, the recommended plant density is from 30,000 to 40,000 plants/ha. Maize grown for silage is seeded densely in order to achieve a high density from 80,000 to 100,000 plants/ha.
Effective seeding rate
The effective seeding rate depends on the optimum density (related to the characteristics of the cultivated plant) and on the resources mobilized (equipment and/or work force) at the farm level, which should be adapted to the requirements as much as possible. However, in the case of lack of resources, a compromise must be found between effective seeding date, rate and method in order to reduce production potential as little as possible. It may also be necessary to decrease seeding rate in order to be able to carry it out on time, on the whole farm.

Plant density
Final plant density depends on the effective seeding rate and germination rate. It is therefore essential, when calculating the optimum seeding rate and carrying out seeding, to take into account the germination rate, which must be measured in advance.

Germination test
Seeding aims to achieve an optimal plant density, so before starting it is essential to perform a test to ensure good seed germination. This test can be done very simply by placing one hundred seeds, well-spaced, in an absorbent paper folded like an accordion (\\\\\\) or between two layers of paper or cotton placed on a dish and kept wet in all cases. Some days later, you just have to count the germinated seeds with normal appearance in order to calculate the germination rate. If this rate is very low (less than 10%) the seed lot must be changed. A poor germination rate (<40% for small seeds, <60% for big seeds, even after treatment to remove eventual dormancy) implies that the number of seeds at seeding must be increased in order to compensate for poor germination. After emergence, if necessary, thinning can be conducted to reduce plant density.

Main crop seeding method
The seeding method is related to plant characteristics and to resources available on the farm at seeding time. It must allow the establishment of the seed under good conditions, at an optimal depth and with the desired spatial arrangement.

The seeding method used for crops (and associated plants) is usually determined in order to allow fast seeding on the whole farm, with optimal rates. The resources to achieve the optimal seeding rate must be mobilized as much as possible. When the available resources are not sufficient, production potential may be reduced due to a delay in establishment. Then, we must find the best compromise to ensure, as fast as possible, seeding at rates and with a spatial arrangement of plants that allow the maintenance of a good production potential and ensuring crop management thereafter (weed control, etc.).
Manual or mechanized seeding

Manual seeding is very laborious, but allows free arrangement of crops and associated plants, at any time, and requires no equipment (a simple stick or a small angady is sufficient). It must be done carefully, otherwise it may be irregular and heterogeneous (variable seeding depth, poorly respected alignments, etc.). The equipment, such as a hand jab planter or a wheel seeder, allows seeding in rows or in holes more easily and faster than manually, at low cost. Mechanized seeding allows seeding large surfaces quickly and homogeneously. However, it is expensive (a significant investment in equipment) and does not always allow the arrangement of plants as desired. Nevertheless, we can seed main crops and associated species simultaneously by using a seeder equipped with three hoppers, including one for associated, pure or mixed cover species (seeders Vence Tudo®, Semeato®). It is also possible to seed cover plants by broadcast seeding with centrifugal seeders, mechanical or manual (small portable hand crank seeder).

Row seeding, hole seeding, and broadcast seeding

Seeding in rows or holes is much more time-consuming than broadcast seeding (especially in small-scale farming). However, it allows the spatial arrangement of plants in order to optimize plant density and to place seeds in optimal conditions. In addition, it greatly facilitates maintenance work (maybe weeding in year «zero», weed control, etc.). On the other hand, broadcast seeding, which is rapid and inexpensive, does not allow positioning the seeds (so no possibility of spatial arrangement, seeds are placed at the surface). In addition, broadcast seeding on a vegetation cover is only possible with small seed plants (sorghum, millet, etc.), but for species with large seeds it is only possible if they germinate well under a vegetation cover (as rice). Most large-seed species require a light tillage in order to obtain favourable germination conditions. Therefore, they cannot be broadcast seeded in direct seeding systems.

Main crop seeding depth

Optimal seeding depth is mainly related to plant characteristics and in particular to seed size. The optimal seeding depth is about 3-4 times the size of the seed (0.5 to 1 cm for small seeds, and approximately 2.0 cm for large seeds). Excessive seeding depth greatly delays emergence and is harmful to the crop. An excessively superficial seeding or at the surface (broadcast seeding, leaving the seeds uncovered) may result in poor emergence.

Main crop variety

Different varieties of a single species can have very different behaviours. Biomass production can vary greatly from one variety to another, crop cycles can be longer or shorter, habit can change, photosensitivity may vary, root system can be very different, etc. Thus, the variety itself determines crop association possibilities, competition risks, cropping conditions, agronomic interest, etc. So, it is important to know the different varieties and use the varieties selected for their ability to produce high biomass, under specific conditions.
Establishment of direct seeding cropping systems
Selection of the operational sequences

The variety is generally chosen at the same time as the system, in particular for:
• its cycle adapted to climate, water regime and cropping system;
• its habit, size and vigour in the beginning, which affect its abilities to withstand weed and/or associated plant competition;
• its requirements in terms of fertility;
• its capacity to resist insect attack and diseases.

However, the variety effectively seeded, can be different from the one that was planned, in order to adapt to unexpected constraints such as seed availability or late seeding date (in this case, a variety with a shorter cycle and/or low sensitivity to photoperiod is preferable).

A «last minute» supply of a new seed variety is, however, difficult to do in practical terms. It is therefore very important to prepare it in advance (by ensuring an early supply, an early plot preparation, and mobilizing the resources needed for seeding, etc.), in order to allow the chosen variety to be sown in good conditions.

When a change of variety is necessary but impossible to achieve, crop production objectives must be reduced, and along with them fertilization and seeding parameters. We must then try to maximize the production of associated plants, to ensure good functioning of the DMC systems during the next year.

Plant spatial arrangement
The spatial arrangement of the main crop should be as regular as possible. However, it may be interesting to arrange plants in a particular manner to facilitate crop management (weed control, in particular) and plant association or succession.

3.2. Establishment of plants under crop association, relay or succession to maximize biomass production

A single crop does not occupy all the space, all year long. It leaves some space, at least temporarily, which can be used to establish plants able to increase biomass production and perform ecosystem functions. However, these plants must be managed carefully to avoid generating harmful competition with the main crop, and if possible to live in synergy with it. For this, the choice of species and varieties (and, therefore, the choice of cropping systems) is fundamental (cf. Volume II, Chapter 1), as well as plant arrangement, in space and time.

Climate and water regime determine the possible production period according to species and varietal characteristics of the cultivated plants. Many cover plants are chosen for their ability to grow under marginal conditions. They can strongly extend the biomass production period: during the cold period in temperate climates, as far as possible during the dry season when it is marked; and/or produce very quickly at the beginning of the rainy season or during a «small» rainy period in bimodal climates, with two rainy seasons.

Depending on climate and water regime, crop association and succession can be more or less manageable.

The shorter the cropping period (long dry season and/or cold season), the
Establishment of direct seeding cropping systems
Selection of the operational sequences

lower the possibility to modify the seeding date of the associated plant. It could not be established under satisfactory conditions, even if it is able to grow better, under marginal conditions, than the main crop. The management of competition between the main crop and the associated plants is mainly done by plant spatial arrangement and localized fertilizer input.

When the possible cropping period gets longer, it is possible to shift the timing of seeding of associated plants, which allows an increase in the seeding rate, as long as you follow a spatial arrangement that limits the competition with the main crop.

For even longer cropping periods, intra-annual successions can be established, which can allow the association of plants during the first cycle. If the cropping period is long enough, we can seed the second cycle after harvesting the first one, but if necessary, you can seed the second cycle «in relay» a few weeks before harvesting the first crop.

The basic principle is to ensure good establishment of the main crop and to adjust seeding parameters of the associated plants in order to optimize their production, without generating harmful competition to the main crop. These parameters are the «guidelines» that manage crop association in space and time. They are based on dynamic interactions and offer many possibilities to adapt to farm constraints.

Thus, seeding parameters of associated plants are determined in interaction, according to:

• the effective seeding date and rate of the main crop;
• the climate and water regime, which determine the potential period of plant growth;
• the resources available at the farm to perform work;
• the respective cycles of the associated plants: a cover plant with a short-cycle must be shifted (in time and/or space) vis-a-vis a longer cycle crop;
• their effect at the beginning: stylosanthes, for example, which starts slowly can be associated earlier with the crop, while a plant like brachiaria which starts rapidly should not. In general, large seed plants start more quickly than small seed plants;
• the habit of associated plants: a twining cover plant risks climbing and stifling the main crop, thus it should be space shifted vis-a-vis the crop;
• the level of soil fertility and fertilizer input: a demanding crop on poor soils has a much slower growth than a more tolerant cover plant, thus seeding should be shifted to avoid competition. However, we can avoid delaying cover crop seeding (to ensure a better biomass production) by providing fertilizers (mineral and/or organic) placed near the crop seed that we aim to promote.

In practice, the easier way to manage and to implement is to adjust seeding date and plant spatial arrangement.

“Guidelines” to manage crop association

For a given agronomic unit (climate x water regime x fertility), and a given cropping system, crop association management is carried out dynamically, in space and time by «playing» with:

• associated plant seeding date, which allows an easy crop association management in time;
• plant spatial arrangement, seeding method and rate, which enable the best use of the space;
• localized supply of fertilizer, variety selection, establishment method and seeding depth of associated plants, which allow “playing” dynamically on the relative growth rate of plants.

Seeding Stylosanthes three weeks after rice, in year «zero»
Seeding date of associated plants

As for the main crop, the earlier the associated plants are seeded, the higher the biomass production (and possibly seed production). However, early seeding associated plants may promote competition with the main crop and even more so when the seeding rate is high. Depending on conditions (climate, water regime, fertility) and systems (and thus plants to be associated), seeding the cover plant associated with a crop can be done as follows:

- **Simultaneously with the main crop.** Simultaneous seeding is easy to perform, either manually or mechanically, in an easily accessible plot. It facilitates the rapid establishment of the associated plant, which can quickly cover the soil, reducing weed pressure and erosion. However, simultaneous seeding increases the risk of competition with the main crop, which sometimes requires measures to prevent detriment to the main crop (use a long cycle species/variety, with a slow start, and leave enough space between plants, control the cover plant during vegetative stage, etc.). However, simultaneous establishment of the main crop with a cover plant, can complicate crop weed control: herbicide use can only be done with a selective herbicide that kills all the different plants, which is hard to find, manual weeding is very slow, and care must be taken to avoid damaging cover plant seedlings. However, in some situations, such as a climate with a very long dry season, with a very short production period, simultaneous seeding is sometimes the only solution to enable the cover plant to produce sufficient biomass to justify its establishment;

- **From two weeks to one month after seeding the main crop.** Shifted seeding greatly reduces the risk of competition between the associated plants and the main crop. It also allows crop weeding before plant cover establishment, which simplifies weed control, and allows the quick establishment of the cover plant during weeding) on “clean” crop interrows;

- **At the end of the cycle, during the last month of the main crop cycle** (avoiding disturbance of the plots during...
main crop flowering which is a sensitive period). This type of relay seeding allows establishing a cover plant «relayed» in the main crop when the crop succession is difficult to implement, but only a minimal period may be used by the cover plant (as long as it is established in time, before main crop harvest). This practice is an intermediate alternative between crop association and succession (the relayed plant grows better in succession than associated with the main crop). It allows optimizing the cover plant production: after an establishment phase (of several weeks) which is done under the crop, the cover plant starts quickly after the main crop harvest. Relay seeding is usually done by broadcasting, because row or hole seeding is hardly feasible in a crop at an advanced stage, except for low-density crops (such as maize). This practice is of particular interest when the cover plant must «connect» itself to the groundwater at the beginning of the dry season, and when soil surface humidity, after harvest, is insufficient. This type of seeding is also very interesting in relay cropping of plants that lose their leaves at the end of the cycle (such as soybeans): the falling leaves cover the seeds and facilitate their germination, and the crop allows light to pass to young cover plants.

The establishment of the associated plant in the middle of the main crop cycle is difficult to do and generally is of no interest. It cannot grow properly because of the shading effect of the main crop, which is supposed not to allow sufficient light for the development of weeds after 40 days, and is too weakened by a long time in the shadow, preventing growth after the main crop harvest.

### Examples of seeding date of associated plants

Stylosanthes that starts slowly can be seeded simultaneously with rice without competition risk, except on soils where limited fertility greatly slows rice growth. In practice, on all type of soils in year «zero», it is better to establish stylosanthes during rice weed control (from 15 days to three weeks after seeding). It is very difficult to perform weed control without damaging young stylosanthes seedlings that would have been seeded with rice.

Oat seeding under relay cropping in soybean, before the leaves fall
Establishment of direct seeding cropping systems
Selection of the operational sequences

**Plant spatial arrangement and seeding rate**

Besides seeding shift, plant spatial arrangement is a key tool in crop association management. By acting on the distances between plants, we can ensure that the main crop can develop without competition and the associated plants can grow, cover the soil and produce high biomass. Plant spatial arrangement allows optimizing production.

At similar rates, plants arranged in staggered rows are more distant from each other than plants seeded in «square». Consequently, they are less competitive, use resources better and cover the soil better. So, they intercept more light and produce higher biomass. However, this seeding method is very time consuming (even if it facilitates subsequent crop association management), and is very difficult to mechanize.

![Seeding in single rows](image1)
**Seeding in single rows**
Plants in rows ("square" arrangement)

![Seeding in single rows](image2)
Seeding in single rows. Plants in staggered rows
Lower competition and better soil cover

At similar rates, growing in double rows can promote the development of the associated plant by providing it with more light, without penalizing the main crop. Such an arrangement facilitates crop association management, reducing the working time required for its maintenance and optimizing production (grains and biomass). Its manual establishment is a time consuming task, but it can be easily mechanized.

Row orientation can also promote associated plants: East-West row orientation (when it is compatible with the slope) follows the movement of the sun, and allows plants associated in the main crop to receive more light than a North-South row orientation.

**Examples of plant spatial arrangement**

In the Malagasy South West, maize + *Vigna umbellata* association should be performed at low density and in staggered or double rows (preferably) to reduce competition for water, the main limiting factor.

The rice established in a poor soil after soil smouldering must be established on the smouldered trenches, and in double rows. The inter-row can receive a legume, less demanding in terms of fertility.
In the case of systems that combine cereals and legumes, planted in single or double rows, the main agronomic functions performed by these systems vary from one row to another. When crop association is successive, it is important to shift the seeding rows from one year to another, in order to cultivate the cereal on the legume rows of the previous year, and vice versa (except when the cereal is planted on smouldered rows). This practice allows stopping mono-cropping in rows and promoting cereal growth with nitrogen inputs provided by the legume of the previous season. This is the case of the “robust” system that associates maize with a twining legume (dolichos bean, cowpea, *Vigna umbellata*).

When you want to establish a pure crop in succession, seeded at a higher rate (like rice), the management of the previous crop in double rows can cause problems. Nitrogen management, in particular, must be done in order to provide this element preferentially to the former cereal rows, and in smaller quantities to the former legume rows. For the cropping systems that alternate crop association (cereal + legume) and cereal mono-cropping, crop association management in single rows can be preferable (especially if the fertilizer cannot be furnished locally).

In the case of cover plant mixture, by associating grasses with legumes, and seeding them in rows, it is better to alternate cover plants in rows rather than having rows with a single species. For example, in maize + brachiaria + cajanus association, it is better to have two mixed rows brachiaria + cajanus between maize rows, rather than alternate maize, brachiaria and cajanus rows.

### Method of seeding or establishment of associated plants

Plant spatial distribution supposes that the seeding method enables and therefore establishes plants either in rows or in holes. Therefore, broadcast seeding the main crop does not allow an adequate crop association management because of plant spatial arrangement. It is primarily reserved for seeding crops in relay at the end of the cropping cycle, or in succession.

Rooting plant cuttings is the only possible establishment method for sterile plants (like Bana grass) and the most economical way for plants whose seed production is extremely expensive such as perennial peanut.

The establishment of cover plants by cuttings or stem fragments is very time consuming and requires a lot of vegetal material and it is hardly mechanized, but it allows a much faster regeneration than cover plant establishment by seeds. It is very interesting to maximize biomass production in a short period. However, the risks of competition increase. The distance between plants must be increased and/or rooting plant cuttings operation should be delayed.

### Seeding depth

Optimum seeding depth depends on seed size (3 to 4 times seed size). Deep seeding delays emergence and can even lead to seedling death (the smaller the seed, the easier the seedling emergence). It should be avoided, except when we wish to seed a cover plant earlier (or eventually simultaneously with the main crop) for reasons of accessibility to the plot, but plant emergence should not be too early, in order to avoid its competition with the main crop. However, this practice needs a good technical mastery of seeding, and can only be done with plants that can cope with deep seeding. For example, brachiaria can be seeded simultaneously with upland rice, at a 4-5 cm depth.
Varieties used

The characteristics of cover plant varieties must be taken into account to «adjust» seeding parameters. The cycle and vigour of varieties at the beginning strongly influence crop association management:

- the varieties with a fast startup (vigour at the beginning) and/or short cycle are more competitive in the beginning of the cycle than long cycle varieties, and must be shifted in time or space. However, they quickly cover the soil which offers protection against erosion and weed control and maximizes biomass production during a very short period. They are also able to complete their cycle in constraining climates during a very short growing period;

- on the other hand, long cycle and/or slow startup varieties are not likely to compete with the main crop, but must be seeded earlier and/or at a higher rate than short cycle varieties if we want to cover the soil quickly. In climates with a long dry season, long cycles may be favourable for their production in marginal periods, as long as these plants can use deep water. Otherwise, we should use shorter cycle varieties, able to complete their cycle under dry conditions.

Plant habit must also be taken into account:

- twining varieties can climb associated plants and strongly compete for light and/or make harvest difficult. They must be seeded away from the crops, and/or later, especially if they have a short cycle. Unlikely, erected or creeping varieties cannot climb up crops once they grow higher than these varieties, and can be seeded closer to the crops and earlier;

- erect tall plants intercept the light of the smaller plants, which are unlikely to compete with the main crops.

We should also be interested in:

- plants with a strong root system and rapid development (such as brachiaria) that are very competitive for water and nutrients. They must be seeded away from the crop plants, especially in dry climates and/or on poor soils;

- certain plant varieties that tolerate difficult conditions (waterlogging, low fertility, shading, etc.) better than others.

Finally, photoperiodic varieties resent delay in establishment, responsible for their rapid decrease in production and in system performance. Moreover, they cannot be used in off-season and, therefore, must be associated with crops, without possibility of crop succession or relay cropping.

Variety selection is done after the choice of cropping systems, in parallel with the choice of plants to associate (species and variety of the main crops) and the determination of a specific operational sequence. The characteristics of the chosen varieties must render cropping systems possible and must optimize production. Technical seeding parameters (date, method, spatial arrangement, rate, depth) are adapted to the characteristics of species and varieties, which are themselves chosen to be compatible with the planned operational sequence. However, in case of an “accident” (like a delay in main crop seeding), the varieties and all the operational sequences can be changed in order to adapt to the new situation (the cropping system itself may need to be changed).

In practice, changing the variety just before seeding is difficult to do due to the availability problem of suitable seed varieties. When it is not feasible, we will try as much as possible to change see-
Establishment of direct seeding cropping systems
Selection of the operational sequences

In the same way, if we have not been able to supply the initially chosen variety in time, technical seeding parameters (or even systems) have to be adapted to the available variety that will be used.

Localized fertilizer application at seeding

The amount of fertilizer to add during seeding is calculated within the context of the fertilization management of the whole crop, and more generally within the context of plot fertility management over time. The amount of fertilizer required according to crop and soil is presented in the detailed technical sheets (Volume V.). They are based on different interacting factors:

- established crops;
- production objectives;
- soil fertility at seeding, which is related to initial soil fertility and to previous crops;
- available resources and level of tolerable risk;
- involved risks (climate risk, pests, theft, etc.).

If nitrogen inputs must be balanced over the whole cycle, phosphorus, potash and micro-nutrient requirements are important at the beginning of the cycle. These elements must be provided at seeding or during plot preparation.

In addition, mulch at the beginning of decomposition «consumes» nitrogen (used by bacteria to initiate the mineralization process) and on cereal crops it can lead to nitrogen «starvation». This nitrogen “starvation” risk is even more important when mulch is composed of grasses and its degradation is not very advanced. In such cases, urea supply is essential at seeding in order for crops to avoid suffering from a deficiency which is very damaging at the beginning of the cycle.

The addition of mineral or organic fertilizers at seeding can be done as follows:

- in the field, homogeneously: distribution of organic fertilizers and/or broadcast application of mineral fertilizers, which can be done manually with small portable spreaders or by mechanized methods; or
- in a localized way, close to the crop seeds for promoting growth, which improves fertilization efficiency and limits competition by cover plants or weeds. Manure (or compost) and/or mineral fertilizers are then applied into the seed holes (manual seeding) or in the seeding rows (mechanized seeding). Placing the fertilizer a few centimetres below the seeds allows rootlets to quickly access it after germination (but seems to damage microflora). In all instances, we must avoid putting mineral fertilizer in direct contact with seeds because it could burn them;
- by coating seeds or pelleting cuttings.

Localized fertilization or coating allows promoting a plant compared to another and represents an additional «tool» for crop association management. On low fertility soils, the application of fertilizers near the crop seed, especially if it is a demanding crop, allows its normal development and to be more competitive.
It is then possible to seed associated cover plants at a higher rate and/or earlier, allowing a faster soil cover- rage and a better biomass production.

### 3.3. Seeding operation

#### Seed treatment

**Dormancy-breaking**  
Seeds of numerous species naturally present dormancy, therefore, it may be necessary to eliminate it before seeding (especially if seeds are used shortly after their production). Depending on the species, breaking seed dormancy may be performed by prolonged soaking in water (eventually hot), scarification or soaking in an acid-bath. Treatment conditions depend on species and are presented in the technical sheets of cover plants (cf. Volume III.). After this operation, it is essential to carry out a germination test again to ensure its effectiveness.

**Seed inoculation (legumes)**  
Atmospheric nitrogen fixation by legumes is done in symbiotic crop association with specific bacteria (rhizobium). When installing a new species of legume on a plot where it had never been cultivated, it is often necessary to inoculate the seeds of this legume with an adapted rhizobium strain (according to species, cf. Volume III.). This inoculation can be done by spreading on the plot a few kilograms of soil from an area where these bacteria are present, or by seed inoculation. This can be done by obtaining the appropriate rhizobium and mixing it with the seeds in a suitable container, and adding an «adhesive» (gum arabic, honey, or another binder). Rhizobium is a living organism, thus, it is necessary to carry out this inoculation in a cool place, sheltered from the sun, and just before seeding (all seeds should be seeded on the same day, in wet conditions). These seeds should not be treated with toxic substances (pay particular attention if necessary to use insecticide or fungicide treatment: Use only products slightly toxic to humans, as Thirame®), nor mixed with acid fertilizers.

**Seed coating**  
Coating seeds with a fertilizer such as rock phosphate (thermophosphate, Thomas phosphate slag, Hyper Barren) dolomite or limestone and micronutrients, is a particularly efficient method that requires only very low doses of fertilizer (a few kg/ha). It favourably modifies the immediate environment of the seed (pH increase), and therefore allows a proper establishment of young plants. It also promotes the infestation of legume roots by rhizobium and thus helps to establish symbiosis. Seed coating can be done very simply by adding fertilizers (powder) and micronutrients when inoculating legume seeds. It can also be done by soaking the seeds in water (maybe pre-germinating these seeds) and then mixing them with fertilizers. As for inoculation, coating must be done just before seeding.

**Fungicide and/or insecticide treatment of seeds**  
During the first years of transition from conventional to DMC practices, it may be necessary to protect crops against insect and fungi attack (damping-off disease, particularly on legumes). As the aim is to reduce the use of pesticides to a possible minimum level, seed treatment is an efficient option that allows minimizing their impact on soil biological activity and plant health. This seed treatment is done by simply mixing products with seeds, taking the usual precautions when handling these toxic products (the use of gloves is essential).

For large quantities, a mixing drum (simple barrel in which an aperture has been made, crossed by an off-axis crank and placed on a four-leg structure) is very useful. In all cases, this treatment should not be systematically used. It must be calculated according to pressure from pests, sensitivity of cultivated plants and crop intensification level (for example, using fertilizers in order to obtain high production makes the treatment essential when facing a medium pest pressure).
Establishment of direct seeding cropping systems
Selection of the operational sequences

Seeding

Seeding in rows or in holes into straw mulch
Seeding into a straw mulch is done with minimal disruption of the vegetation cover and with as little as possible soil displacement. In the case of manual seeding, a simple hole opened with a stick or a small angady is sufficient for placing the seeds inside the soil. Conventional hand jab planter allows accelerating the work and reducing soil disturbance, because it only opens a hole for the seed. Mechanical seeders for large field crops work by opening the straw on rows. If well adjusted, soil disturbance is minimal (less than 3% of the surface). Tool pressure (whether an angady or a mechanical seeder) should be adjusted in order to place the seed in the soil (not in the straw), at a suitable depth (which depends mainly on the seed size, but can also serve as an «adjustment» to avoid competition between plants by delaying germination).

Broadcast seeding
For small-seed species, seeding can be done by broadcasting directly into the straw. This can be done in a crop (establishment of cover plants at the end of the cycle, manually or using a fertilizer spreader), after or during harvest in the case of mechanical harvest (covering with chopped straw distributed over the surface by a combine). The amount of seeds to be used in the case of a broadcast seeding is higher than for seeding in rows or in holes, but the operation is done much faster.

Planting cuttings and stem fragments. Pelleting
Planting cuttings or stem fragments allows a faster regrowth of plants than by seeds. It is the only possible establishment method for certain plants (like Bana grass which is a sterile hybrid) and the cheapest for plants whose seed production is very expensive (as for Arachis pintoi for example). In general, propagation by cuttings is done by preparing cuttings with at least three nodes («eyes»). These cuttings are implanted in the soil where an aperture was done with a small angady. The cutting is installed in the hole, by leaving two nodes inside the soil, and one or more nodes above the ground surface. The hole is closed by applying moderate pressure with the foot. The technique is the same for stem fragments (for grasses). Just dig up the plants (before flowering), cut the aerial part at 20-25 cm and break the stem, keeping two or three fragments per plant and the roots (cut at 10-15 cm).
To facilitate cuttings or stem fragment regrowth, it is interesting to use the pelleting technique when installing them in the soil. To do this, simply mix in a bucket 1/3 of water, 1/3 of cow dung and 1/3 of very clayey soil. We can also add micronutrients and mineral fertilizers, in particular phosphorus (Hyper Barren, Diammonium Phosphate (DAP), etc.). Cuttings or stem fragments are soaked in this mixture and directly installed in the soil. Pelleting allows plants finding a favourable environment for their development, thanks to the fact that roots are directly in contact with the nutrients needed for their growth. The appearance of rootlets is faster (after only a few days) and regrowth is better.
3.4. Seeding summary

Seeding is a crucial step of the operational sequence, which determines plant density and affects plant growth for the whole cycle (and may even influence the following cycle). The main crop must be seeded as soon as possible, once the useful rains are sufficient to ensure proper plant establishment.

When associating crops, the risks of competition between crops and cover plants are managed in priority by:
- seeding date of the cover plant (depending on the main crop seeding date, which allows modifying plant cropping period);
- seeding rate and plant spatial arrangement (which can allow modifying plant cropping in space);
- variety choice (cycle, habit, requirements, etc., that influence in a dynamic way the relationship between plants, in time and space).

Localized fertilization, seeding depth and cover plant establishment method also allow "adjusting" plant density parameters of the different species and reducing competition risks.

All these parameters must be adjusted «in parallel» in order to achieve an optimal plant density, maximizing production potential. They offer numerous possibilities of technical adjustment that can allow addressing several farm constraints encountered during the establishment of a cropping system.

Examples of adjustment possibilities of a «robust» system: maize + twining legume

The system maize + twining legume (dolichos bean, cowpea or Vigna umbellata) is a very interesting system: simple to establish, highly profitable, high biomass production, etc.

The operational sequence can be adapted in different ways, to a very large number of situations:
- in the dry climate and relatively poor soils of the South West region of Madagascar, maize is seeded after the first rains, at a low rate (1.0 m x 1.0 m). A leguminous plant (preferably dolichos bean) is seeded simultaneously (35,000 holes/ha), staggered or in double rows, allowing it to establish properly, without competing with the cereal. The «white» dolichos bean is very interesting for its taste, long cycle and high biomass production during the dry season;
- at medium altitude, on «moderately rich» soils, maize is seeded after the first rains, at a medium rate (20,000 holes/ha), preferably in double rows (two rows of maize with a spacing of 0.5 m every 2.0 m; seed holes in the row with a distance of 0.5 m), which allows a better production of the associated plant (in particular when its seeding is shifted). Legume seeding is usually done at the same time as maize, with a rate of 25,000 holes/ha. However, a two-week seeding shift may be necessary in case of soils with low fertility (without localized fertilization), when using a maize variety with a relatively long cycle or if we install as an associated plant, a very twining species/variety (Vigna umbellata, for example);
- in the highlands, this crop association is only possible with a short cycle cowpea («David» variety), seeded at the same time as maize so that it can complete its cycle before the cold season. Maize is seeded as soon as possible for the same reasons (its cycle prolongs rapidly when temperature drops). Seeding rates are the same as the ones at medium altitude and can be increased on «rich» soils (tightening rows);
- in the humid South East, cowpea is preferable than other legumes because of its better tolerance to waterlogging. Crop association is managed the same way as at medium altitude, with greater flexibility on seeding dates.
3.5. Some mistakes to avoid at seeding

Several easy to avoid mistakes, are nevertheless common, especially in the early years that are a learning phase and a transition period from conventional to DMC systems, and these changes require some time for adaptation.

So, we just have to plan the activities properly, to anticipate and to be cautious during the seeding operation in order to:

**Avoid late seeding**
Late seeding, which is very penalizing, is often due to a delay in the campaign preparation, in particular in terms of seed supply and plot preparation. Therefore, we just have to anticipate the campaign in order to be prepared to seed after the arrival of the first useful rains.

**Avoid seeding on wet soil when the rains are not yet established**
Conversely, in year «zero», we must avoid seeding into wet soils (or seeding pre-germinated seeds into dry soils) while the rains are not yet sufficiently steady and a dry period is feared. Soil moisture activates germination but seedlings dry out quickly in the absence of rain.

**Avoid seeding poor quality seeds**
Seed supply must be done on time, making sure we get vegetal material of good quality. Therefore, we must make provision of good varieties on time, and check the germination rate of these seeds early enough to be able to change them if necessary (without delaying seeding).

**Avoid seeding in «dirty» plots**
Plot preparation must be done early enough to allow early seeding. However, we must ensure, at the time of seeding, that the plot is «clean», without plants in a vegetative stage that are not effectively controlled (poor control of perennial weeds or regrowth of annual weeds between their treatment and seeding date). Otherwise, it is imperative to clean the plot very quickly (to avoid seeding delay) and to grow plants under good conditions, without competition from weeds.

**Avoid disturbing the soil at seeding**
During the first years of «training» (when the importance of this factor is not well recognized), the fear that the seedling cannot pass through a thick mulch, the lack of carefulness and/or the poor mastery of direct seeding tools can lead to significant soil disturbance. This disturbance harms the functioning of direct seeding and generates particularly strong «pollution» by weed seeds emerging at the time of crop germination, which greatly disturbs weed control.

4. Crop maintenance

System selection, plot preparation and seeding aim to place crop plants under the best conditions (in particular by controlling weeds and ensuring good water and mineral supply). Once the seeding is done, crop maintenance should allow maintaining optimal conditions. These interventions during cropping offer the opportunity to adjust or rectify when conditions do not evolve favourably (errors in the establishment, climatic accidents, pest attacks, deficiencies, etc.). They must be adjusted according to actual crop development, and for this, they require specific and regular monitoring. In particular, this monitoring is done on plant density evolution, deficiencies and possible lack of nutrients, weed development and pest pressure. In the case of an occurrence of a significant constraint, it is essential to respond very quickly in order to conduct operations to eliminate it before it has a significant impact on the crop.
4.1. Replacement of missing plants after emergence

To optimize biomass production, essential for the proper functioning of the direct seeding system, it is important not to leave “empty spaces” in the crop. Thus, if after emergence we observe that some places are very poor in terms of seedling emergence (due to poor seed quality, damping-off disease, etc.), it is necessary to re-seed in the “empty” places. Similarly, re-seeding is recommended to fill any «empty» space, due to an accident (destruction by animals, localized flooding, etc.), even late in the season. Re-seeding can be done with the same species as the seeding if we consider that it is not too late and that crop production is still possible. If it is too late, re-seeding must be done with one or more species (shorter cycle crops or cover plants). Filling these “empty” spaces is essential not only to ensure high biomass production needed for direct seeding, but also not to leave room for weeds that will produce seeds and thus might «pollute» the plots. It is very easy to do it manually but more difficult mechanically.

4.2. Thinning

Conversely, for crops such as maize or sorghum, it is best not to leave too many plants that compete for resources (water, nutrients, light). When seeding has led to excessive plant density (more than 2 plants per hole), it is recommended to manually pull the most underdeveloped plants, and to keep in each seeding hole, only the two better developed plants.

4.3. Fertilization

The choice of fertilization level to apply is done by taking into account a large number of agronomic and economic parameters together, such as:
- plot fertility at the time of crop establishment (which depends on the initial fertility and its potential to improve, and on the previous cropping systems);
- cultivated species (selection is largely determined by the possibility to provide organic or inorganic fertilizers);
- production objectives (related to the crop plant and soil fertility);
- input costs.

Fertilization is assessed early in the season, as a whole. Most of the fertilizer is provided at seeding (or before, on the cover plant). During cropping, fertilizer input is generally limited to a nitrogen supplement and then micronutrients, when deficiencies appear. These inputs, which are part of the fertilization plan can/should be adjusted according to the actual conditions of the cropping operation. Thus, we may decide during cropping:
- to abandon additional input of urea in case of an «accident» (poor weed control, pest attacks, etc.) that has greatly limited production potential, or, conversely;
- to provide micronutrients when crop development is limited by such a deficiency;
- to increase predicted nitrogen inputs when plant development is very good but can still be greatly increased by such an input (for example, urea during rice booting stage).

With such contributions, during the vegetative growth stage we have the advantage of doing it, with limited risk, on a crop at an advanced stage, and that can have a very significant impact on total production (seed and biomass).
However, the optimum fertilization to provide in the case of a plot in year «zero» of DMC preparation, usually with a low level of fertility that has to increase, is very different from the optimum fertilization of a plot under installed DMC systems, in which nutrients are significantly more available, and whose stable production must simply be maintained.

**Fertilization in year “zero” of DMC system preparation**

In year “zero” of DMC preparation, fertilization input should ensure high biomass production to «prime DMC pump».

The selection of crop associations and successions will take into account the initial fertility of the plot and the possibility of providing nutrients. According to nutrient cost, and performance expectations of the different crops on different agronomic units, we can:

- either cultivate a demanding plant (such as rice or maize) after increasing fertility (soil smouldering practices, fertilizer input, etc.);
- or grow plants capable of developing without added fertilization (bambara groundnut, cassava) that are associated with undemanding cover plants with high biomass production.

The minimum amount of fertilizer input that allows obtaining sufficient biomass to properly install systems under DMC, vary according to environments and crops.

In general, fertilization is provided only to the most demanding plants: rice and maize. Potatoes, a very demanding crop, is highly fertilized and generally provides a good profit, but produces very little biomass.

On moderately rich tanety soils (including hydromorphic tanety soils of the South East), the “low” fertilization of rice or maize corresponds to 150 kg/ha of NPK fertilizer (11-22-16) and 100 kg/ha of urea, equivalent to 65 units of nitrogen, 15 units of phosphorous and 20 units of potash, per hectare.

A higher fertilization (300 kg/ha of NPK fertilizer and 100 kg/ha of urea, i.e., 80 units of nitrogen, 30 units of phosphorous and 40 units of potash, per hectare), when it is safe, allows obtaining a much higher biomass production and yields, as well as «installing» DMC rapidly.

On the soils of the plains which are not prone to flooding, river banks and baiboho, a simple urea intake (100 to 110 kg/ha or about 50 units of nitrogen/ha) ensures good production. However, a more complete fertilization (100-20-15) enhances production and facilitates the management of crops under DMC during the following season.

In alluvial flooded rice fields, rice fertilization levels are the same as on soils which are not flood-prone.

In contrast, on flooded organic rice fields, it is necessary to provide phosphorus. Thus, the minimum fertilizer input required by rice is 50-15-0, and a more complete fertilization corresponds to 60-40-15.

Finally, in very organic rice fields (peaty) of the South East, it is necessary to provide potassium as well as nitrogen and phosphorus. “Low” fertilization corresponds to 50-15-20, and “high” fertilization to 60-30-40.

Below these «low» levels of fertilization, biomass production of these crops is often too low to allow direct seeding in good conditions next year.

Less demanding crops like beans or soybeans can be grown without mineral fertilizers but require manure application (3-10 ton/ha) on poor soils of tanety.
Soybeans, which are more demanding, benefit from mineral fertilizer supply (150 kg/ha of N-P-K). These crops produce a relatively low biomass. Biomass production must be ensured mainly by associated cover plants.

In general, supply of manure (or compost) allows an interesting production gain in all crops, and is highly recommended.

Finally, the less demanding plants (cassava, bambara groundnut) can be grown without fertilizers, associated with undemanding cover plants, which ensure biomass production.

If the biomass produced during year «zero» of DMC preparation, with the levels of fertilization described, is insufficient to conduct direct seeding systems in good conditions, we must grow crops with the same level of fertilization, or even higher, or change the cropping system in order to ensure high biomass production.

Conversely, if the biomass produced is sufficient and allows establishing DMC systems in good conditions, fertilizer application may be reduced in the following year. If biomass production was very high, it is even possible to simply compensate for losses due to exportation, as in well-established DMC systems.

**Maintenance» fertilization on established direct seeding plots**

Once soil fertility is restored in well-established DMC systems, it is necessary to manage it in order to avoid soil depletion. This is done by:

- cultivating complementary plants in association or in succession, which have different requirements and provide different agronomic functions (legumes for nitrogen fixation, grasses for restructuring the soil and recycling nutrients leached into the depths, etc.); and
- returning exported nutrients to the soil.

Apart from exceptionally rich soils, it is essential to return a minimum amount of nutrients to the soil (organic and/or mineral fertilization), to compensate for its exportation by crops or forages. In the absence of such restitution, production is necessarily made at the expense of soil becoming progressively poorer (even faster as yield and nutrient exportation are higher).

This limited fertilization (which can be adjusted according to the profits of the previous year) is an important precaution to conserve soil fertility sustainably.

The calculation of the amount of fertilizer to provide in order to compensate nutrient exportation during the previous year is based on the average nutrient export by the crops concerned, proportional to their production.

The following table gives an indication about the high variability of nutrient exportation values by different plants (bibliographical synthesis).

The use of the median (indicated in red) provides a rough evaluation on the amount of nutrients to provide in order to compensate losses by exportation. This table also shows the high amount of nutrients exported by straws if they are not returned to the plot, especially regarding potash.
Establishment of direct seeding cropping systems
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Special case

A previous association of grass(es) with legume(s) such as maize + twining legume, planted in rows or double rows, leads to a strong irregularity in terms of nitrogen availability. The legume has provided a large amount of nitrogen to the soil and decomposed itself rapidly, while the grass did not fix nitrogen and decomposed slowly, causing a risk of "nitrogen-hunger".

For a cereal or cotton crop, nitrogen fertilizer (urea) must be provided (especially at seeding) mainly to the rows that received the grass during the previous cycle in order to compensate for the low local availability of nitrogen (especially in the beginning of the cycle).

### Average nutrient exportation by crops

<table>
<thead>
<tr>
<th>Nutrient exportation by crops</th>
<th>N (kg/ton)</th>
<th>P (kg/ton)</th>
<th>K (kg/ton)</th>
<th>Ca (kg/ton)</th>
<th>Mg (kg/ton)</th>
<th>Si (kg/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice (paddy)</td>
<td>12-16-20</td>
<td>2-3.5-5</td>
<td>1-2.5-4</td>
<td>0.5-0.75-1</td>
<td>1</td>
<td>15-17.5-20</td>
</tr>
<tr>
<td>Rice (straw)</td>
<td>10-12.5-15</td>
<td>1-1.5-2</td>
<td>15-25-35</td>
<td>3-3.5-4</td>
<td>2-2.5-3</td>
<td></td>
</tr>
<tr>
<td>Maize (grains)</td>
<td>15-20-25</td>
<td>3-3.5-4</td>
<td>2-3.5-5</td>
<td>0.2</td>
<td>0.5-0.75-1</td>
<td>2.5-3.75-5</td>
</tr>
<tr>
<td>Maize (straw)</td>
<td>13-14-15</td>
<td>1-1.5-2</td>
<td>15-22.5-30</td>
<td>1-1.25-1.5</td>
<td>0.5-0.75-1</td>
<td>1</td>
</tr>
<tr>
<td>Sorghum (grains)</td>
<td>13-16.5-20</td>
<td>3-3.5-4</td>
<td>1-2.5-4</td>
<td>0.3</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Millet (grains)</td>
<td>15-17.5-20</td>
<td>2-4-6</td>
<td>4-4.5-5</td>
<td>0.2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Wheat (grains)</td>
<td>20-27.5-35</td>
<td>3.5-4-4.5</td>
<td>2-7-12</td>
<td>1-2-3</td>
<td>1-2-3</td>
<td>3</td>
</tr>
<tr>
<td>Brachiaria ruziziensis</td>
<td>10-20-30</td>
<td>1-2.5-4</td>
<td>8</td>
<td>2-3.5-5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Soybean (grains)</td>
<td>50-75-80*</td>
<td>5-8-11</td>
<td>15-17.5-20</td>
<td>3-9-15</td>
<td>2-5.5-9</td>
<td>5-7.5-10</td>
</tr>
<tr>
<td>Pinto peanut (grains)</td>
<td>40-45-50*</td>
<td>2-4-6</td>
<td>4-6-8</td>
<td>0.3</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Beans (grains)</td>
<td>35-37.5-40*</td>
<td>4-4.5-5</td>
<td>18-21.5-25</td>
<td>2-3-4</td>
<td>2-3-4</td>
<td>10</td>
</tr>
<tr>
<td>Vetch (total)</td>
<td>25-27.5-30*</td>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Stylo. guianensis (fodder)</td>
<td>25-27.5-30*</td>
<td>2-2.5-3</td>
<td>10-20-30</td>
<td>10-15-20</td>
<td>3-3.5-4</td>
<td>1.5</td>
</tr>
<tr>
<td>Potato (tubers)</td>
<td>3-4.5-6</td>
<td>0.5-1.75-2</td>
<td>2-4.5-6</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Cassava (tubers)</td>
<td>2-4.5-5</td>
<td>0.4-0.7-1</td>
<td>1-3.5-6</td>
<td>0.5</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Sweet potato (tubers)</td>
<td>4-5-6</td>
<td>1</td>
<td>4-5.5-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton (grains)</td>
<td>20-22.5-25</td>
<td>5-7.5-10</td>
<td>10-15-20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>1-1.5-2</td>
<td>0.2-0.35-0.5</td>
<td>1-1.25-1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabbage</td>
<td>3-4-5</td>
<td>0.5-0.75-1</td>
<td>1.5-1.75-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit trees (fruits)</td>
<td>3-4-5</td>
<td>0.5-0.75-1</td>
<td>2-3.5-5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Nitrogen fixed by legumes 12 - 16 - 20: low value - median - high value

To obtain the equivalent in P2O5, K2O, CaO, MgO and SiO2, multiply respectively: P by 2.29; K by 1.2; Ca by 1.4; Mg by 1.66 and Si by 2.
Establishment of direct seeding cropping systems
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Just for comparison, nutrient input by fresh cattle manure varies (strongly) from 3 to 15 (8, on average) kg of N per ton of fresh manure (about twice as much as dry manure), from 0.5 to 3 (1.5, on average) kg of P per ton of fresh manure and from 2 to 11 (on average 6.5) kg of K per ton of fresh manure. Poultry manure is richer in nitrogen (11 kg/ton of fresh manure) and phosphorus (4 kg/ton) but poorer in potassium (3.5 kg/ton).

Periods for fertilizer application
The principal amount of fertilizers must be applied to major crops during the first years. In general, all the applications of organic fertilizers and of poorly soluble fertilizers (natural phosphate, etc.) are done at seeding. Phosphorus and potassium application are also done at seeding because the plant needs it in the beginning of the cycle. The addition of micronutrients is preferably done at seeding when risks of significant deficiencies have been diagnosed, or eventually upon the appearance of deficiency symptoms (when such deficiencies were not predictable).

Only nitrogenous fertilizer application on grasses is split due to its high solubility, to the risk of leaching losses, to the risk of plant physiology unbalance by excessive doses and to the needs of plants during all their vegetative growth period, from seeding to flowering.

One part is provided at seeding, representing about 1/3 to 1/2 of the total nitrogen input. The rest is distributed according to plants and their management: after each mowing in the case of forage, at tillering and at bolting in the case of rice, at the beginning of male flowering in the case of maize, etc.

These inputs must be adjusted according to the vegetative stage of the plant and general management of the crop. An additional supply of nitrogen can be very profitable (and a little risky) in a well-managed crop, without any accidents, but that seems to be deficient in nitrogen. Conversely, it is not reasonable to provide fertilizers to a badly managed crop (very late seeding, invasion by uncontrolled weeds, etc.) whose yield potential is low.

When seeding a cereal into a mulch essentially composed of grasses, a minimum of 30 kg N/ha (preferably 50 kg/ha) must be provided at seeding to avoid the risk of nitrogen blockage by the mulch at the beginning of its decomposition.

When a rice crop that produced 4 ton/ha, the amount of major elements to provide in order to compensate for nutrient exports are about 64 N, 14 P or 10 K, 64 N, and 32P2O5.

According to available fertilizers, we can provide, for example, 70 kg/ha of DAP (18% of N and 46% of P2O5 or 12.6 N and 32 P2O5), 112 kg/ha of urea (46% of N or 51.5 N) and 20 kg/ha of KCl (60% of K2O or 12 K2O).

If there is only NPK (11N-22P2O5-16K2O) and urea, we must use 145 kg/ha of NPK (or 16 N, 32 P2O5 and 23 K2O) to provide sufficient P, and complete with 105 kg/ha of urea to return the nitrogen exported by rice. In this case, we provide K twice more than is necessary!

Balance between mineral elements
Plants need a balanced diet. In addition, mineral elements interact and their absorption by plants depends on the relative concentration of one element compared to another. The most well-known competition is the one between the major elements: excessive nitrogen or excessive phosphorus blocks potassium absorption by the plant. An excess of nitrogen also blocks many micronutrients (B, Cu, Zn, S, Fe, etc.) and there are other competitions between micronutrients and major elements. Phosphorus, for example, is blocked due to an excess of manganese, iron or aluminium (Al3+). There are also synergies, such as magnesium which is more readily absorbed when phosphorus and nitrogen are present in high quantity and which facilitates phosphorus absorption.

It is therefore essential to provide a balanced fertilization, correcting, if necessary, soil imbalances (maybe with an amendment in year «zero»). In practice, plant diversity (capable of mobilizing different elements when
they are poorly soluble) in DMC systems, fertilization of plant/soil systems as a whole and, when possible, diversification of the fertilizers used, allow to obtain and maintain a balance between mineral elements.

Some mistakes, regarding fertilization, that should be avoided

Avoid providing insufficient fertilization to the selected system
In year «zero» of DMC preparation, on low fertility soils, the main mistake to avoid is to provide insufficient fertilization that does not allow a good enhancement or a high biomass production by the chosen system. Taking into account the high cost of fertilizers, the temptation is often strong to reduce the dosage, but this «solution» is very risky if it falls below a minimum threshold necessary to ensure a production that can capitalize the provided fertilization, or at least to produce biomass that allows cropping later under DMC, in good conditions (fertilization is then seen as a medium-term investment in these systems). If the investment, at a minimum level required to run the system, is too high or too risky, it is essential to change from the selected system to a less demanding one, which will ensure the necessary biomass production, while applying (or not) less fertilizers.

Avoid to “spare” nitrogen fertilizer on a grass mulch
A grass mulch that is starting to decompose immobilizes nitrogen in the first stage. In this case, if you do not provide nitrogen at the beginning of the cycle (at seeding) to a cereal or a cotton crop it causes a high risk of «nitrogen hunger» which is very damaging to the crop. Therefore, if the mulch was not treated early enough to avoid nitrogen blockage, it is essential to provide nitrogen at seeding.

Avoid maintaining a high fertilization level on a system established late or without weed control
Another mistake to avoid is to maintain a high fertilization level on a system where conditions forced late seeding. Late seeding increases climatic risk (higher risk when the climate is more constraining). Beyond a certain deadline, the risk becomes too high and cannot be supported. In this case, it is necessary to reduce the risk by decreasing the level of fertilization (and production objectives) if possible (i.e., if biomass production is sufficient to maintain this system under DMC, with a low fertilization level), or by changing the system, if necessary. Similarly, fertilizer application should not be done if the means to control weeds (which also benefit from fertilization) are not available.

4.4. Control of annual weeds

In rainfed crops, on tanety and in a very noticeable way on rich soils such as baibo ho and rice fields with poor water control, where a water layer cannot be maintained, weed pressure is heavy. Weed control is planned according to the whole cropping system: selected crops, crop associations and successions, and several operations of the operational sequence. Generally, the control of annual weeds in established DMC systems is done quite simply by:

• no soil disturbance, which keeps seeds under unfavourable conditions for germination;
• maintaining a permanent plant cover, dead or alive, which prevents weed emergence or «suffocates» it;
• gradually reducing the seed stock, and possibly;
  . allelopathic effects of plants used in the cover.

Therefore, in properly established DMC systems, weed control does not generally demand specific measures after the establishment of appropriate cropping systems on a well-controlled vegetation cover. However, weed control can be problematic in year «zero» of DMC preparation, when the vegetation cover
In the case of insufficient biomass...

If after a year «zero» of DMC preparation the produced biomass does not seem sufficient to control weeds in the succeeding crop, a good solution is to re-conduct an easy to maintain cropping system and with high biomass production (such as maize + dolichos bean, for example). Hand-pulling or light weeding is then used to control weeds at lower cost, without generating excessive soil disturbance. High biomass production (and possibly the allelopathic effects of the plants used) will control the weeds in the next crop, which can be a plant for which weeding is more difficult (like rice). Similarly, after an «accident» which leads to poor soil cover, it is of interest to «recharge» DMC systems by establishing a cropping system where it is easy to control weeds and with high biomass production.

Tillage does not control weeds by itself and must be complemented by other measures at seeding and/or after emergence.

In established DMC systems, that after an «accident» did not maintain sufficient soil coverage, the use of tillage must be avoided as much as possible because it has the additional disadvantage of accelerating the mineralization of the plant litter that was rebuilt by the DMC system during the previous years, and it quickly loses the benefits gained.

Thus, either after tillage or direct seeding into a thin mulch, weed control measures should be anticipated, and particularly when:
• weed pressure is heavy;
• the crop is sensitive to competition from weeds, and;
• it makes intervention difficult: manual weeding of upland rice, for example, is much more time consuming than maize.

The choice of crops/associations whose maintenance is relatively easy, with high biomass production and able to control weeds naturally (maize + legume or cassava + stylosanthes, for example) facilitates crop maintenance during the time needed to produce a high biomass, which will control weeds during the following season.

Beyond the choice of crops and crop associations to establish, tillage in year «zero» may be used to control weeds in the absence of biomass to cover the soil. It helps to reduce weed pressure by killing the already emerged annual plants. However, it has the disadvantage of re-creating good conditions for the germination of buried seeds and for the vegetative multiplication of some perennial plants with rhizomes or stolons.

Weed control by the vegetation cover
Photo: K. Naudin
This control can be done in several ways, depending on the available resources and constraints:

**Mulch supply**
If biomass is available near the plots (we can also concentrate the biomass on one part of the plot), it can be used to create mulch, which helps to control weeds. This requires that the mulch is sufficient to completely cover the soil at least during the first 45 days of cropping. However, if the mulch is not enough (or if it decomposes too quickly), weeds can develop, taking advantage of the improvement in soil fertility.

However, supplying a plot with straw represents a lot of work (particularly significant when straw has to be transported over long distances), which is sometimes difficult to carry out when establishing crops (especially if the plot has been conventionally worked) and only possible if biomass is available within a reasonable distance.

**Pulling or weeding**
In direct seeding into a thin mulch, that allows weeds to grow, weeding (which tills the soil surface) must be restricted as much as possible. If weeds are few and/or the plot is small, it is better to pull seedlings by hand, without disturbing the soil surface, in order to take advantage of the benefits of direct seeding. This pulling work is, however, very time consuming (in particular on difficult maintenance crops, such as rice) and cannot always be performed on time. Thus, it may be preferable to carry out weeding when no other weed control method is accessible to farmers.

For crops relatively easy to weed, such as maize, pulling is preferred rather than weeding, even on large plots, as long as sufficient manpower is available when needed.

**Using pre- or post-emergence herbicides**
The importance of using herbicides, and therefore the choice of the strategy to control weeds is done according to:

- weed pressure (and, thus, the environment);
- crop type (some crops such as rice are more difficult to weed and less tolerant to competition than others, like maize, for example);
- manpower availability and cost;
- herbicide availability and cost.

Herbicides have the advantage of allowing good weed control but are expensive. Pre-emergence herbicides must be applied systematically (before knowing the exact weed pressure) under restrictive application conditions (quickly after seeding, in wet soils). Their selectivity, relatively good, may depend on conditions at time of application (climatic conditions that slow emergence, such as drought that can induce toxicity symptoms to crops). Moreover, their effectiveness is reduced in established DMC systems due to the vegetation cover and the high level of organic matter.

Post-emergence herbicides have the advantage of being applied according to the exact weed pressure, with the possibility of localized application, and under application conditions less constraining than pre-emergence herbicides. However, they are very difficult to use when associating plants with different characteristics, and their selectivity depends of the application conditions, being capable of causing toxicity and disturbing plant health.

The reduced number of certified active ingredients in Madagascar limits the possibilities of chemical control against weeds, particularly for certain crops or associations. Even when herbicides are available, the scarce
resources of farmers do not always allow them to be bought and they should only be used if the economic profitability is very high and/or the available workforce cannot control the weeds effectively. Moreover, the negative impact of herbicides on plant health (disruption of protein synthesis, herbicides not being totally selective) means that the use of these products during cultivation (pre or post-emergence) should be limited as much as possible. Therefore, the possibilities and the benefits of using herbicides vary according to the situations and the crops:

**In rice crops**

Rice is one of the most difficult crops to weed, especially as it often grows in heavy weed pressure environments. Thus, the use of herbicides is particularly recommended in rice fields with poor water control, where a water body cannot be maintained at the beginning of the cycle, and on *baiboho* (in the absence of sufficient mulch capable of reducing weed pressure).

In these environments, the control of broadleaf plants and annual sedges can be done by applying 2,4-D amine (720 g to 1,080 g/ha) at least 25 days after rice emergence (risk of phytotoxicity on young plants). As weeds get older, they become more resistant, which means that we must increase the dose. At weed seedling stage, a lower dose (360 g/ha) is sufficient and due to the reduced risk of phytotoxicity risk on rice. This post-emergence herbicide has several advantages: it is applied only if necessary, it is very cheap (less than 6,000 ariary/ha = € 2.3/ha for a dose of 720 g/ha) and controls a wide variety of broadleaf weeds.

In the case of plots which are highly infested by perennial sedges with storage organs (*Cyperus rotundus*, *Cyperus esculentus*) particularly difficult to control, their emergence is delayed by a thick mulch. The application of bentazon in these conditions allows the control of these plants long enough so that rice becomes able to control them. This herbicide is no longer available in Madagascar.

Regarding annual grasses, there is no selective post-emergence herbicide for rice able to control them and certified for use in Madagascar (while waiting for cyhalofop-butyl that would be very interesting to import). When annual grass pressure is heavy, it is recommended to apply pendimethalin as pre-emergence herbicide, capable of controlling these weeds as well as some broadleaf plants. The average application dose of pendimethalin is 1,500 g/ha (cost: 75,000 ariary/ha = € 28.3/ha). However, in case of extremely heavy pressure from plants such as *Echinochloa sp.* and especially *Ischaemum rugosum* that can be estimated according to the number of seeds present on the soil, it is necessary to increase the dose to 2,500 g/ha (cost: 125,000 ariary/ha = € 47/ha). Oxadiazon is another interesting pre-emergence herbicide which is used at 1,000 g/ha and allows controlling most grasses and broadleaf plants, while being selective of certain legume crops.

In addition to their high cost (and their impact on the environment), these herbicides have the disadvantage of being pre-emergence herbicides which must be applied on the seeding day (when we do not yet know what will be the exact weed pressure, and thus, being sometimes applied unnecessarily) and on wet soils. This reduced application range can pose problems for the cultivation in large areas in case of random climate, even if it is possible to use them in early post-emergence. However, in areas heavily infested by annual grasses, manual or mechanical weeding is extremely difficult to do efficiently and requires a lot of work. The benefit of using an herbicide is increased.

On *tanety*, where weed pressure is often inferior to that in rice fields or on *baiboho*, the use of herbicides is not recommended as much as in these «rich» environments.

In case of broadleaf weed infestation, the use of 2,4-D amine (720 to 1,080 g/ha), which is inexpensive, as post-emergence herbicide is very profitable.

For grass control on *tanety*, the use of pendimethalin, which is very expensive (even at 1,500 g/ha) compared to production potential, can only be justified in certain situations where weed pressure by *Digitaria horizontalis* or *Rottboellia cochinchinensis* is very heavy and cannot be controlled by weeding or pulling. The high cost of this herbicide reduces the profitability of upland rice on environments highly infested by grasses. Thus it is better to first grow a crop easier to weed, such as maize associated with a legume.
In maize (or sorghum) crops
In maize sole cropping (or sorghum) systems we can control weeds chemically, with molecules such as atrazine. However, maize (or sorghum) under sole cropping, but not associated, does not make part of the systems recommended in this practical handbook, where crop association allows increasing revenues and biomass production (and consequently supplying the direct seeding «motor»).
When associated with a grass (Brachiaria sp. or Eleusine coracana in particular), the use of 2,4-D (540-720 g/ha depending on the stage of the weed) is possible and highly efficient to control broadleaf weeds. The use of atrazine at a reduced dose (0.5 to 1 kg/ha, being adapted locally according to soil and climate) is also possible for maize + brachiaria association.
In the case of maize (or sorghum) associated with a legume, it is difficult to weed chemically with the active ingredients available in Madagascar. Pendimethalin can be used to control grasses (and some broadleaf plants). However, its high cost only justifies its use in very specific situations (like on baiboho with very heavy pressure by grasses and in the absence of available manpower). On highly infested plots we can use selective pre-emergence herbicides, if available, like metolachlor and alachlor, in maize crops (and rice crops). It is then possible to seed a legume in association, after 3 - 4 weeks (the persistence of these herbicides varies from 15 to 20 days).
In most cases, in the absence of mulch or only the presence of a thin mulch, weed control in maize (or sorghum) associated with a legume can be done by slight weeding or by hand-pulling. A single pulling/weeding is usually enough to obtain good control, and maize rapidly emerges above weeds that could regrow, and associated legumes cover the soil quickly, interrupting by this means seed germination and new plant growth.

In legume crops
Bentazon was used at 960 g/ha, after the 2-leaf stage of soybeans, beans or pinto peanuts (but not on cowpea, Vigna umbellata, Stylosanthes guianensis, etc.). Since its removal from the market, there are no certified herbicides in Madagascar that can be used on legume crops to control broadleaf plants.
Fluazifop-P-butyl, used as post-emergence herbicide (and thus applicable on request, according to observed weed pressure) at a dose of 62.5 g/ha, at a reasonable cost, is also no longer available in Madagascar. From now on, for the control of weed grasses in a pure legume crop, only pendimethalin (1,500 g/ha in pre-emergence) might have an advantage, despite its high cost, in case of heavy infestation (Digitaria sp., etc.). In the case of the absence of these herbicides, or the means to buy them, mulching is of interest if biomass is available, especially since it greatly increases production (particularly with bambara groundnut).
Generally, on these crops weeding or pulling once is enough if their development is satisfactory and there is limited interest in the use of herbicides.
In cotton crops
The cultivation of cotton in the first year of entry into the direct seeding system is not recommended (due to low biomass production). Weed control is done mainly by preparing a large amount of mulch for the following years. It should be noted the interest in sorghum mulch to control sedges that often disturb cotton crops.

In cassava crops
Herbicide use for weed control in cassava crops is not recommended, especially since it is highly advisable to associate cassava with *Brachiaria sp.* or *Stylosanthes guianensis*.

In potato crops
As the potato is often a highly fertilized crop (because it is demanding) weed pressure can be heavy. However, there are no certified herbicides in Madagascar for this crop. The provision of mulch to the soil is highly recommended if biomass is available. Crop association with a cover plant (oats, for example) remains the most interesting practice.

Using a total herbicide between crop rows, with protection
For crops at low density (maize, cotton, etc.) or grown in double rows, it is possible to use a total herbicide (glyphosate) by applying it between crop rows (or double-rows), before seeding associated cover plants, with protection to avoid touching the cultivated plants. This band spraying of inter-rows can be done manually with a backpack sprayer, or mechanically with a suitable machine.

Some mistakes to avoid on weed control
Some basic precautions can reduce weed control errors. In particular, we must organize ourselves in order to:

- avoid applying herbicides in bad conditions: intense heat, wind, risk of rain in the following hours. Spraying in the early morning often avoids these adverse conditions. We should also avoid applying herbicides by using dirty water or at high pH and, in general, respect the recommended conditions of use of these products. Unfavourable conditions for herbicide application may render the products inoperable and lead to serious difficulties for weed control thereafter (particularly to control perennial weeds in year «zero»);

- avoid seeding a very large surface under dry conditions, on which we have to apply a pre-emergence herbicide. This herbicide treatment should be carried out very quickly after the first rains. Therefore, we must be able to carry out spraying of all seeded surfaces in one or two days.

4.5. Control of associated plants during cropping
The establishment of crops and associated plants aims to maximize the total production by avoiding competition between the crop and the cover plant. However, the cover plant may compete with the crop due to: poor estimation or not respecting the spatial arrangement of plants at seeding and/or seeding dates of the different plants, the slow development of the main crop, a particularly dry year, etc. In such situations, it is essential to slow the development of the cover plant before it starts a detrimental competition with the crop.

This control is usually done by a simple mowing or flattening cover plants early enough to prevent them from dominating the crop. It might not be sufficient in the case of a marked water deficit (associated plant roots still in place and vegetatively active after mowing). Herbicide use may be necessary in this case.
4.6. Control of living mulch plants

The preparation of a living mulch seeks to control it adequately so it does not compete with the crop, but without killing it so it can produce high biomass after the main crop harvest. However, such management is delicate and sometimes the living mulch regrows too quickly, competing with the crop. Regular observation of the plot must be able to detect competition risks in case of too rapid recovery of the cover (especially for water if rainfall is low). In this case, it is necessary to control it during the cropping season, which requires:

- the application of a selective herbicide (such as fluazifop-P-butyl for grass control in a legume crop), is a fast and efficient method but requires knowledge and access to it (cost and availability);
- the application of a total herbicide in the inter-rows (using protection to avoid affecting the crop) of low-density crops, such as maize, or crops established in double-rows;
- mowing the cover plant repeatedly. Some plants like Desmodium or kikuyu can be managed in a living mulch without herbicide, by simple mowing before seeding and then regularly until the main crop dominates the cover plant. This method requires neither investment nor special knowledge and allows exporting partially the cover for animal feeding. However, it is very demanding in terms of work, which can lead to an insufficient or excessively late cover control. It also has the inconvenience of not reducing cover plant competition for water.

4.7. Phytosanitary treatment

The first years of transition from conventional to DMC systems, during the time needed to restore ecological balance and to improve plant nutrition, the pressure by pests on crops can be very heavy. Under certain conditions, the use of phytosanitary treatments during the vegetative stage may be necessary. However, these treatments must be limited as much as possible because of their negative impact on soil life, the ecological balance and plant health, in the medium term. The use of these products must be considered (implying a good knowledge of pests and products) and adapted to each situation. Generally, in Madagascar, given the low availability of pesticides, the use of fungicides (mancozeb) is exceptional and limited only to vegetable crops (tomato, potato) under heavy mildew pressure. The use of insecticides is more frequent, but still limited to the production of particularly sensitive legume seeds and cotton. The treatment is done in case of major attacks after the floral bud stage. The main product employed is deltamethrin at a rate from 6.25 g/ha (0.25 l of product/ha at 25 g of active substance/l) to 12.5 g/ha (in case of thrip attack).

The use of these toxic products requires safety precautions (protective clothing, gloves and mask, rigorous cleaning of equipment and body with soapy water, etc.). The main errors in the use of these products are due to poor knowledge, which can lead to an excessive use and/or under bad conditions, or conversely, a lack of monitoring or reactivity which leads to a delay or absence of the needed treatment.

5. Harvest and post-harvest

Harvest is done when plants have reached their optimal maturity. Harvest on direct seeding systems differs from that of conventional systems, by:

- the need to return all the straw to the plot, as homogeneously as possible, and;
- the fact of having to collect associated plants, sometimes at different stages of maturation, without damaging young plants that might be growing under the crop.
In practice, direct seeding systems that work thanks to a fast turn-over of biomass, aim to maintain it on the plot and to export only the grains. For this, either manually or mechanically, the cut is done as high as possible and all the straw is maintained on the plot or returned to the soil after being threshed. Cutting it high also has the advantage of keeping most of the biomass in a standing position, and making it decompose more slowly than when in contact with the soil, where there is a strong biological activity, and prevents it from being washed away by rain or wind. It also allows a homogeneous distribution of crop residues. Thus, in direct seeding, harvesting a crop is already one of the operations of plot preparation for the next crop. In contrast, conventional systems often consider the abundant crop residues as a constraint for tillage and try to export them. Harvest is done at a lower cutting height and straws are exported or burned. Harvesting method (manual or mechanized) has an impact on harvesting conduct and residue management. It also has an influence on the system to establish, which must be harvested according to the adopted means.

5.1. Manual harvesting

Manual harvesting is commonplace in Madagascar, as part of small family farming, with small plots and very limited resources to invest. It has the advantage of not requiring any investment and allowing the harvest of all types of crop association (while being careful not to damage young plants in the case of relay cropping). However, it requires a lot of hard work, and it might be a problem to harvest all the crops at optimum maturity stage if they all reach maturity at the same time. Manual harvesting of plots seeded mechanically (and, thus, quickly) is often problematic. In the case of lack of manpower to harvest, it can be advantageous to shift seeding or to use several varieties with different cycles, in order to allow harvesting during a longer period of time.

Traditional practices vary according to the type of plant and farming habits. They often need to be «adapted» to integrate direct seeding systems with a permanent plant cover better, especially for straw restitution.

**Tall cereals (maize, sorghum, millet)**

Tall cereals are generally harvested spike by spike, leaving the rest of the plant standing on the plot. In crop association, crops usually have a longer cycle than these cereals and are not damaged by this harvesting method, and can climb the canes left in place, particularly the twining legumes (dolichos bean, *Vigna umbellata*, and some cowpeas). Leaving the canes standing in place also slows their degradation, as their decomposition is faster when lying on the ground. Keeping the canes standing on the plot is particularly important in case of heavy pressure caused by termites that decompose them very quickly once they are in contact with the soil. To delay this decomposition, we can, at harvest, fold the cane in two, which delays their fall when they become weak, so that they lay on the ground due to wind.

**Short straw cereals (rice, wheat, oats, etc.)**

Manual harvesting of short straw cereals can be done:

- panicle by panicle or spike by spike with a small knife, which is time consuming but allows a «staged» harvest (a mixture of varieties, for example) and especially, it keeps in place most part of straws.
- by mowing with a sickle (which might allow selecting plants at maturity) or a scythe (faster but not allowing a «staged» harvest). In these cases, a significant portion of straw is removed from the plot to carry out threshing that can be manual, by stamping, or mechanized. Such a threshing method «in a fixed position» concentrates biomass on a part of the plot (or outside). In conventional agriculture, this straw is often burned, or eventually exported to feed animals. In direct seeding, straw must be installed on the plot in the most homogenous way possible, an excessively thick straw layer is inconvenient for seeding (and fertility management), while conversely an insufficient cover does not allow supplying the litter properly neither
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controlling weed efficiently. To limit straw transport, direct seeding cut should be made as high as possible, which is not always easy to do manually, and can slow the harvest operation and make threshing difficult.

**Legumes with aerial grains (soybean, green bean, dolichos bean, cowpea, Vigna umbellata, etc.)**

As for short straw cereals, hand harvesting of legumes may be done:
- pod by pod, which keeps the vegetative parts of the plant on the plot and allows a «staged» harvest (which greatly increases production in the case of plants whose flowering and fruiting stage is spread in time like cowpea), or;
- by mowing with a sickle and threshing (usually manual). It is a faster practice, especially for plants with small grains, but with direct seeding the tops have to be transported back and spread on the plot (even if they represent a less significant biomass than the one of cereal straws).

**Legumes with buried grains (pinto peanuts, bambara groundnut)**

Harvesting buried seed legumes is done by pulling the plants. In direct seeding, these legumes position their pods on the soil surface, just under the mulch, making the pulling operation easy and fast, while only disturbing the soil slightly.

As for the other legumes, threshing is done «in a fixed position» because in direct seeding it is necessary to bring the tops to the plot in order to supply the plant litter.

**Roots (cassava) and tubers (potato, sweet potato, etc.)**

Manual harvesting of roots and tubers is done by pulling, which implies soil disturbance. This disturbance is limited in the case of tubers, due to the fact that in direct seeding they develop on the surface, under the mulch. Soil disturbance is slightly more significant in cassava that develops below the soil surface.

Hand-harvesting bambara groundnuts on a couch grass cover
Pods on the surface, under the mulch
However, a good soil structure maintained by direct seeding and the production of tuberous roots, mainly on the surface horizon, means that pulling is easily done, without disturbing the soil deeply. In all cases, the aerial parts (if they are not consumed) are not transported and can be left on the plot after harvest. For tubers such as potatoes, which are conserved after harvest but cannot be conserved in the soil after maturity, harvesting is done only once. In contrast, cassava is difficult to conserve (a few days without post-harvest treatment) but can be conserved in the soil during very long time. Its harvest can be distributed over several months and done as and when required.

5.2. Mechanized harvesting and threshing

Mechanized harvesting and threshing require a significant investment and are only possible on large plots, but can be done on large areas in a short time. Thus, harvest at optimal stage of maturity can be done on all large plots or farms.

The use of a combine for harvesting and threshing «in a mobile position» allows the restitution of all straws (and seed coats) to the plot, in a very homogeneous way. The cutting height is easily adjustable, leaving most of the biomass in a standing position and thus slowing its decomposition. It is also possible to seed some crops (small seeds) at the time of the previous crop’s harvest, by broadcast seeding or thanks to distributors installed in the combine. These seeds will be lightly covered with straw distributed behind the combine.

Harvesting a crop in which a cover plant was installed in relay, a few weeks before harvest, is also possible. However, mechanized harvesting does not allow (or it is very difficult) harvesting associated crops or mixed varieties, at different stages of maturity.

In addition, mechanized harvest of underground plants (tuberous roots and tubers, legumes that bury their grains) generates a strong disturbance of soil by the tools used. Thus, it does not respect a basic principle of direct seeding mulch-based cropping systems. When these plants have a strong economic interest, they may be introduced into DMC cropping systems, as long as they do not appear too frequently in succession, and that they are followed by systems with very high biomass production, in order to restart quickly the functioning of DMC systems.

6. Conclusions

In direct seeding mulch-based cropping systems, the operational sequences mainly aim to increase the efficiency of the cropping systems that ensure the essential agronomic functions. Choosing an operational sequence is a complex process, which is done simultaneously with the selection of crops and associations/successions to establish, depending on the available resources and goals.

Seeding is a fundamental step that influences all the operations that will be carried out subsequently, and has a major impact on the final production. In all cases, the operational sequence must be adjusted to each stage, according to real conditions on the plot, after the previous operations. These adjustments require a precise monitoring of plots, thanks to an acute observation of plant development and a regular risk assessment of crop damage. They demand a high reactivity and adaptability to unpredicted events, which might happen during a crop cycle.

Upland rice after maize + dolichos bean
Volume II. Chapter 3
How to propose direct seeding mulch-based cropping systems adapted to farmers’ needs and constraints

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1. Objectives

The principles for the creation of DMC systems allow the identification of a wide range of technically possible systems for a given agronomic unit (cf. Volume II. Chapter 1.). When designing systems for a given area, the main socio-economic constraints are also taken into account to develop a range of technical proposals adapted to local conditions. However, this range of systems must deal with the wide variety of farms in the same area, therefore it should propose systems with several main crops, various intensification levels and requirements in terms of environment and adaptable technical knowledge, a flexible level of livestock farming integration, etc. The intervention at farm level consists in selecting from the technically feasible systems those which are the most suitable and interesting. Within the framework of real advice at the farm level, the aim is to propose to farmers individually, for any given situation (plot x farm x terroir), a choice from a minimum of two (if possible) or maximum of five systems (if more, the farmer’s «choice» becomes difficult). For those systems that are identified, we must explain their advantages, their meaning in terms of costs, inputs, equipment, risks, amount of work and organization, etc., but also in terms of the expected results and benefits (presented in the technical sheets per system, volume V.). This work can be done at the scale of the plot that the farmer wishes to work, and where we try to identify the systems at this plot level that are best adapted to the farm. However, it is preferable to organize production in terms of the farm as a whole, in order to optimize resources by making proposals for the different plots, on multiple agronomic units. On the farm, the selection of systems for all the existing plots is done in an iterative manner (by «round trips» from one plot to another) to distribute production the best way possible in order to optimize resources and meet farm requirements.

In all cases, the final choice lies with the farmers and the work consists in informing them about the possibilities offered by DMC systems (and their restrictions), at the plot where they wish to work, but also on the several usable agricultural units (especially when direct seeding may allow re-cultivation of plots unusable on conventional systems).

2. Different types of DMC systems

In order to facilitate selection, systems can be organized according to four main types, allowing a better adaptation to the farmers’ needs, wishes and constraints. They allow the achievement of objectives and ensure food self-sufficiency (in particular, in terms of rice) and fodder production if necessary at the farm level, while allowing soil and production improvement and minimizing risk (and therefore investment) as much as possible.

Thus, these systems may allow:

1. rice production. These systems are intended to address a major concern and frequently a priority issue of Malagasy farmers: to ensure their self-sufficiency in rice. Rice production can be done at the plot level:

- every year, in situations where it is possible (rice fields, baiboho), knowing that such systems are often demanding in terms of inputs and work force;
- once every two years, alternating with a year of high production of biomass for the proper functioning of direct seeding systems, which may help to reduce inputs and work force requirements, but need to plan annual crop rotation; or
- after two or more years for soil improvement on the poorest plots, while trying to minimize inputs.

Baiboho: alluvial or colluvial soil, rich in silt (Malagasy term)
2. the production of grains or tubers every year (with the possibly of rice production once every two years). These systems provide a regular income at the plot level, while gradually improving the soil in order to reduce input requirements.

In both types of systems, exported biomass to feed animals is often at the expense of agronomic performance. Apart from the case of intensive systems with very high biomass production, it is preferable to keep it as much as possible on the plot, for at least the first years, in order to initiate the direct seeding «pump» which ensures its main beneficial functions.

3. the production of grains or tubers alternating every two years with an improving/fodder plant. This third type of system has the advantage of allowing a more rapid improvement of soils and weed control, while minimizing inputs. However, it has the disadvantage of not producing every year. In areas with high population density, where available land is scarce, farmers may be reluctant to leave their land without production every two years. Nevertheless, such systems can be of interest even in those situations, especially because of their capacity to improve soils. Thus, we must divide the plot into two in order to ensure a high production every year (and assured of rapid soil improvement) on half of the surface, rather than getting low yields every year in the whole plot. These systems, thanks to their high biomass production, allow a partial use of the produced biomass for animal feeding, which can be very significant for farmers, particularly during certain periods of low fodder availability.

4. establishment of pastures and/or trees. This last type of system is presented preferably to farmers or areas with degraded and fragile soils, which should be protected, at the terroir level. They allow the establishment of good quality forages that play an important role in soil protection and improvement. The establishment of forages into a crop allows the payment of forage establishment costs. However, in the case of the intensive use of forage, it is essential to provide fertilizers in order to compensate nutrient exportation and to avoid impoverishing the soil even more.

Within the context of the relationship between DMC and livestock farming systems, we can distinguish:

- the systems that produce and partially export fodder during the regular season or the off-season;
- the systems that enable the establishment of perennial forages or the contrary;
- the systems where it is required to leave in place the produced biomass and protect from livestock straying (at least during the first years); and
- the systems that produce non-palatable biomass, which will not be exported even in the case of livestock straying.
Finally, in practical terms, there are two major types of direct seeding techniques:

- **systems on dead mulch**, where crop residues and/or cover plants have completed their cycle or are totally dried by the effect of herbicide or mechanically controlled (using a knife roller, or peeling off i.e.; cutting the roots horizontally a few cm below the soil surface and thus cutting fine layers of the top soil, leaving them in the same position to minimize soil disturbance) and constitute soil coverage. Most of these relatively simple techniques have the disadvantage of requiring cover plant reseeding each year (except in case of natural reseeding); and

- **systems on living mulch** where one is satisfied to control a perennial cover plant during the cropping period but without killing it, so that it re-installs itself after the cropping period. These techniques allow a reduction in the doses of herbicides possibly used and renewal each year without re-seeding the cover plant that remains in place. However, they require good technical skill.

### 3. Characterization of the possible cropping systems

This practical handbook is designed to identify rapidly the systems to propose to farmers and to present their characteristics (performance, application conditions, necessary resources, involved risks, etc.) easily.

Volume I of this “Practical Handbook of direct seeding in Madagascar” presents the principles and functioning of ecosystems cultivated under direct seeding on permanent soil cover and indicates rules for their management.

This volume II is a tool to help the selection of a system to propose to farmers.

Volume III presents the main cover crops/plants of services used in DMC systems in Madagascar, with their characteristics, the environments where they develop, their agronomic interests, their management and the possibilities to integrate them into cropping systems.

Volume IV illustrates the design of cropping systems through a synthesis of the identification work and presents per environment (agro-ecological zone and soil type) the most interesting DMC systems to establish crops rapidly under direct seeding, along with their interests and constraints for the zone of medium altitude climates (600 to 1,100 m) with a long dry season (over 6 months), corresponding to Lake Alaotra and the Mid-Eastern region.

For this zone, it presents for each agronomic unit, the most interesting DMC systems to install rapidly crops with direct seeding, with their interests and their constraints.

Volume V provides examples of efficient and robust DMC cropping systems which can be proposed in many situations. It uses the same pictograms to easily describe them.

Agronomic units are described in Annexe 3, based on fertility levels, soil compaction (which limits their capability to agricultural production), position on the landscape/topographic level, hydric regime and utilization mode. For each agronomic unit, the various systems which can be proposed are presented in tables allowing to progressively make a decision.

For each agronomic unit, the different systems that can be proposed are shown in tables that allow making a progressive decision.
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choice based on: the farmer’s requirements in rice, beans and/or tubers; on their resources (possibility to invest in fertilizers, herbicides, insecticides), and on requirements for forage or straying constraints. These tables show the different possible crop successions/associations, and/or cover plants/annual or perennial forages in the first 2 or 3 years, in order to get into direct seeding systems. The column «observations» also gives information about cropping possibilities after the second year. The choice must be planned through several years, in order to:

• ensure fertility management and permanent soil cover by crop association/succession (intra-annual and interannual);
• avoid the engagement of farmers into systems that would be inappropriate in the medium-term (for example, advising farmers to establish a perennial plant that will require an herbicide for recropping, knowing that they do not have access to this type of product);
• propose systems that aim to improve the soil gradually in the long-term; allowing the growth of demanding plants (rice and maize, for example) on degraded agronomic units, which do not permit immediate cropping, or that would require an input incompatible with the farmers’ resources;
• propose to start with agronomically unattractive systems but with a high economic return, which allows intensification during the following year in order to obtain faster high biomass production, the «engine» of DMC systems.

Each system is then described in a technical sheet presenting its benefits, constraints and possible alternatives.

For each agronomic unit, a summary is presented with the systems, their requirements and agronomic (soil restructuring, nitrogen fixation, weed control, etc.) and economic (profitability, working time) information.

At the beginning of the intervention, the year of direct seeding preparation, which is often done conventionally with tillage, is considered as year «zero». Year “one” corresponds to the first year of seeding on vegetal cover. When the available biomass is sufficient to perform direct seeding (on natural vegetation of *Cynodon dactylon*, for example), we consider that we enter directly into year “one” of DMC.

3.1. Codification of systems

A colour code is used in the tables and pictograms presented in the technical sheets that describe the systems, allowing fast identification of each system constraints and advantages. A text code allows a precise definition of the different systems:

- **crop association** is indicated by «+», either if seeding is done at the same time or at different times (relay cropping: seeding the cover plant or the associated crop a few weeks after seeding the main crop);
- different cropping years (**inter-annual successions**) are separated by «//»;
- **intra-annual succession** is indicated by «/», the second crop is seeded a few days or weeks after harvesting the first one (or some weeks before, in relay cropping), but during the same year.

For example, “Maize + cowpea // rice / dolichos bean” indicates the succession of crops with maize associated with cowpea which is followed, in the following year, by rice followed by dolichos bean in the same year.

*Maize + cowpea*
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3.2. Color code in the tables

To enable an immediate identification of system requirements and constraints, input requirements are listed in one of the first columns of the tables, and highlighted by colors:

- **green** indicates the systems without fertilizers, without herbicides and/or without seed treatment;
- **blue** indicates the systems for which fertilizers, herbicides and/or seed treatment are recommended, but not essential;
- **orange** indicates the systems in which the use of fertilizers, herbicides and/or seed treatment are needed.

The same colors are used to highlight the requirements in the remarks column (subsequent years, alternative systems, etc.).

- A **dark green background** indicates the most interesting systems, recommended in priority.
- A **light green background** indicates the possible systems in certain situations but globally less interesting.

3.3. Pictograms used in system description

System descriptive sheets show the advantages and the constraints of each system and their possible variants.

They present, in particular, input requirements and agronomic and economic interests.

The pictograms placed on the text margins allow the rapid visualization of the main advantages and disadvantages of these systems.

The pictograms are grouped in three types, identifiable by three shapes:

- **circles**, indicating the agronomic importance: soil restructuring, nitrogen fixation, weed control, possibility of using as fodder, favourable as preceding crop for upland rice, requirement decrease in the following year, etc.

- **hexagons**, indicating favorable characteristics of these systems, in the same year of their establishment, in terms of the ease of implementation, low requirements (inputs, work), economic interest;

- **triangles**, indicating the requirements of the system (fertilizers, pesticides).
When the beneficial effects or the requirements are felt in the same year of the establishment of the selected system, the pictograms are left unchanged. On the contrary, when the beneficial effects or the requirements are felt in the following year, pictograms are highlighted by «Next season».

The same color code is maintained in the system selection tables: green indicates favorable conditions, blue indicates situations where inputs are recommended, and orange indicates the essential requirements for a proper functioning of the system. Thus, the following symbols are used:

**For the agronomic importance of the system (improvements in the following years)**

- **very interesting systems for their ability to restructure soil** (very strong root systems and reactivation of biological activity) and to increase organic matter content («injection» of carbon into the soil). The effect is usually felt during the following year but can be seen in the same year of its establishment;

- **very interesting systems for their ability to fix high amounts of nitrogen and/or recycle bases and trace elements** and therefore to improve soil fertility;

- some of these systems can help reduce fertilizer requirements in the following season, or even making it possible to produce the next crop without fertilizer;

- **systems that are very good precedents for rice** can be grown under good conditions in the following season;

- **systems that allow the control of weeds, using plants able to dominate and produce a very high biomass** which will be maintained on the plot (very low export, in particular no stray animals). Some plants also have the ability to secrete substances with allelopathic effects that prevent the development of many weeds.

Weed control can be done from the establishment year, or its effect can be carried to the following year.

Some of these cover plants allow re-cropping in the following year without herbicide.

- **systems able to control or repel harmful insects** thanks to the plants that release repellent or insecticide substances (often members of the family Cruciferae);

- **systems that allow a significant reduction of working time during the following season**, thanks to the fast preparation of plots (no tillage) and good weed control;
• systems with particular interest for livestock production thanks to the possibility of exporting part of the cover plants as forage, often during periods of low forage availability, either in the same year of their establishment or in next year;

• systems that, on the contrary, use cover plants unpalatable to animals, helping to preserve the whole coverage in the case of animal straying.

For the favorable characteristics of the system (establishment year)

• systems possible without inputs in the same year of their establishment. Some of these systems, of particular interest, can be followed by systems without inputs in the following years. However, a minimum fertilizer input is recommended to compensate for nutrient export by grains, tubers or forage;

• systems possible with very few inputs (maybe insecticide, in particular for rice, or herbicide to control a vegetal cover) and that can be followed by systems without inputs or with very few inputs. However, a minimum fertilizer input is recommended to compensate for nutrient export by grains, tubers or forage.

In particular, we find in these systems:

• systems possible without fertilizer, reducing investment in inputs and therefore reducing the economic risk. However, a minimum fertilizer input is recommended to compensate for nutrient export by grains, tubers or forage;

• systems possible without herbicide, thereby reducing the level of technical knowledge needed to use these systems, and which do not require investment to purchase a pulveriser and chemical products which are sometimes difficult to obtain. We can distinguish:
  - well-conducted systems with high biomass production, with plants that start growing rapidly enabling them to suppress weeds without competing with the crop (maize + dolichos bean on baiboho in Lake Alaotra, for example). However, these systems are often difficult to manage and require rapid growth of the main crop and precise management of its association with a cover plant. Some plants, such as oats, have the advantage of controlling weeds during the cropping season, by producing mulch that controls most weeds thanks to its allelopathic effects. Under these conditions, it is sufficient to perform simple hand pulling of the few weeds that may develop (and sometimes even this is not necessary);
  - systems possible without herbicide but that may require hand-pulling weeds once or twice (or eventually a light weeding in year «zero»). It applies especially to systems under tillage in the first year (with crops which are relatively easy to weed and in environments where weed pressure is not too heavy) and systems under direct seeding on a relatively thick mulch but which is not always sufficient to control all the weeds. These systems are more protected thanks to the possibility of using herbicide (especially in the case of insufficient biomass after a low production year, or after animals straying that exported the cover).
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We also indicate:

• low-work consuming systems in the same year of their establishment, in particular at times when manpower is not available;

• systems with high economic returns in the first year (sometimes at the expense of the agronomic interest) and thus obtain benefits that can be reinvested in succeeding crops;

• systems easy to implement, requiring no special knowledge, being very flexible in terms of the cropping calendar and/or being highly robust, i.e., not being too disturbed by «deviations» to the planned operational sequence.

For the requirements and constraints of the system
Fertilization requirements are based on cultivated plants, soil fertility level (and, therefore, type of soil and previous crop), type of eventual mulching (nitrogen hunger risk in the case of cereals on a grass mulch) and crop association mode (type of associated plant, date of establishment, etc.). Pictograms distinguish the need to use fertilizer or not, but do not indicate the doses. Doses are specified in the technical sheets per system (cf. Volume V) with an indicative level of yields that are expected, by environment.

Besides the systems without fertilizers, there are:

• systems for which fertilization is not essential but is recommended because it will greatly increase grain yield (in a cost-effective way) and biomass production (facilitating entry into direct seeding during the next season);

• systems that are not possible without the enhancement of fertility, by the provision of fertilizer and/or use of soil smouldering;

• systems that are not possible without previous soil smouldering;

Finally, we indicate:

• systems and environments for which soil smouldering is highly recommended for its ability to rapidly improve soil fertility at low cost (but with a significant amount of labour);

• systems that produce cereal biomass, and that may cause nitrogen hunger within cereal crops (rice, maize, sorghum, etc.) under direct seeding. Thus, a nitrogen supply to cereal or cotton crops (especially at seeding) will be necessary in the following season.

Herbicide requirements for a given year vary according to: the crops that will be sown as some are more competitive than others when dealing with weeds; the previous crop (or the starting situation), the quantity and quality of biomass in place when seeding (and therefore produced in previous cycles); the existing weed flora and soil preparation method (tillage in year «zero» or direct seeding).
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Herbicide requirements shown here are the ones commonly observed in different systems or with previous crops, in various environments and with good management of these systems (particularly fertilizer application when it is recommended). This therefore implies that:

I) **biomass production was good** during the previous cycle. If not, then we need to consider that we find ourselves in a situation similar to the first year, before the bed for direct seeding has been prepared thanks to the production of a large amount of biomass;

II) **produced biomass was managed properly:** no uncontrolled exportation by animals, nor fire in particular, so that an adequate soil cover is maintained.

It is also important to note that these **herbicide requirement** levels are indicated for the **first year of entry into DMC systems.** After several years of a well-managed direct seeding regime, biomass production for a given system increases due to improved soil fertility, and **herbicide requirement decreases** thanks to soil cover accumulation and reduction of weed seed bank in the soil. Finally, it regards the required levels of herbicide at the current state of mastering of these systems. DMC system development work continues to make improvements in order to reduce these levels.

Thus, there are:

- **systems where herbicide use is recommended**, with two possibilities:
  - systems which are much easier to handle with herbicide, but if managed without herbicide, even if it is often labour-intensive, can be of interest. These are especially irrigated rice systems with poor water control (where weed pressure is relatively heavy and which requires multiple weeding operations executed on time), systems established on natural grass vegetation, with tufts on tanety (controllable by weeding with an angady), or management of kikuyu living mulch to be used by livestock (several mowing operations);
  - systems where the use of herbicide is recommended because it is much more profitable than the use of manpower for manual weed control. It regards especially systems established on crop residues after systems that produce a relatively small amount of biomass (such as bambara groundnut), and/or that decompose rapidly;

- **systems where the use of herbicides is necessary**, also with two possibilities:
  - systems that are technically feasible without herbicide but require significant labour and have a lower technical performance, and where herbicide use is strongly recommended. This is the example of cropping on a Brachiaria ruziizensis or *Cynodon dactylon* dead mulch;
  - systems that are very difficult or impossible to manage without herbicide, and for which the use of herbicide is almost obligatory, such as cropping on a *Cynodon dactylon* living mulch.

We also indicate the systems that can be conducted without herbicide during the first or early years (often corresponding to the establishment of perennial cover plants) but will require the **use of herbicide for re-cropping** (after brachiaria, for example). The information presented allows farmers to be informed immediately about the requirements of the proposed systems, allowing them also to rapidly eliminate systems or crops unsuitable to their resources, and to propose alternatives. Thus, for each situation, it is possible to indicate what level of intensification is required for a specific crop (the one originally requested by the farmer), and if this level is not compatible with the farmer’s resources, it is possible to propose systems/crops compatible with his resources. These systems must allow, after fertility improvement by DMC practices, the cultivation of plants/crops chosen by the farmer with reduced levels of intensification.
Insecticide requirements depend primarily on the crops involved, but also on the environment and on the will to produce seeds or not. Therefore, we can distinguish:

- the systems where insecticide seed treatment is recommended (often expensive);

- the systems where an insecticide treatment during vegetative growth is recommended (usually inexpensive);

- the systems where an insecticide treatment during vegetative growth is necessary (usually inexpensive).

3.4. Tabs that allow the identification of agricultural units and crops

The coloured tabs at the top of the page, in the right-hand margin, allow the rapid identification of the different agronomic units.

Other tabs allow you to identify the different crops presented in the descriptive sheet of the system (by their colour and position) as well as the associated plants.

This quickly provides information that allows the selection of systems to propose to farmers, according to the different situations: usable plants, possible systems, operational sequence to apply, system characteristics (interests, requirements, etc.). This information can easily be presented to farmers, who can then make an informed decision.

4. Identification of systems to propose to farmers according to their objectives, resources and constraints

4.1. Rapid diagnosis at the farm level

Advice at the farm level therefore requires refining the rapid diagnosis made at the *terroir* level and identifying the resources, requirements and constraints at the specified farm. In addition to *terroir* characteristics (climate, pest pressure, pressure on biomass, local «dina» and «fady», fire risk, straying animals or theft, credit and input access conditions, possibilities to commercialize products, etc.), the individual diagnosis must take into account when selecting systems:

- the characteristics of the specified plot(s), cropped or not: agronomic units, how it is used by the farmer (crop cycles, yields, inputs, use of crop residues, etc.), major agronomic constraints (compaction, sealing, fertility, weeds, pests, etc.) risk of accidents (weather, theft, etc.), and type of occupancy, etc.

- the ability of the farmer to mobilize the resources of production (equipment and manpower available, especially during key periods of agricultural work, investment capacity, access to inputs, non-agricultural activities, etc.) and the bearable risk (ability to withstand failure and accepted risk level);

- farm’s needs (rice or a particular crop production, forage needs, etc.), how these needs are covered (distribution of production between the different plots, off-farm resources, etc.) and priorities (priority crops, accepted risk-taking, commercialization opportunities, etc.).
This diagnosis must be done fast (1 to 2 hours/farmer), in an informal way, by discussing and observing the particular plots. Always keeping in mind the systems that are technically possible on the particular agronomic units, diagnosis consists in rapidly observing with the farmer:

- what are the main crops that he is used to growing, that he knows and understands, to simply «adapt» his cropping systems in order to conduct them under DMC;

- if it is absolutely necessary to produce a well-defined crop on a given plot (in this case the farmer must provide the necessary resources), or whether he does not have a predefined idea about the main crop that he will establish in the particular plot, seeking above all to maximize production and profits with the resources at his disposal;

- if it is possible to propose intensified systems, with an input provision (or labour) that the farmer is able to cover the costs, or if not, the risk must be minimized with a low-intensity farming system;

- if the available space allows spending the time needed to restore the soil via the «biological pumps», or if fertility must be increased faster (chemical fertilizers, soil smouldering);

- what is the pressure on biomass on the plot (particularly fodder needs and risks of animals straying);

- if the proposition must be limited, at least initially, only to very simple systems, or if the farmer is willing to move towards more efficient, but therefore, more complex systems (that he must be able to manage), requiring good technical ability.

4.2. Identification of the most suitable systems for the farm

Based on this information, we can identify from the technically possible systems (cf. Volume II. Chapter 1. for the selection of these systems and Volume IV. for the identification of the most interesting systems in each agro-ecological zone) those that are the most suitable and the most interesting to the given conditions (plot x farm x terroir), or to the plots already under cultivation or to enrich plots so far unexploited.

The selection of the most appropriate systems for a given plot is done during exchanges with the farmers, and includes 6 steps (summarized on page 15):

**Step 1. Identification of agronomic units encountered on the farm**, especially those that the farmer wishes to use to try DMC systems. We must be acquainted with their characteristics, resources and constraints. The agronomic unit that takes into account different characteristics of the plot (soil fertility, compaction and water regime) largely determines the possible systems during the early years of transition into the DMC system, and the operational sequence to be implemented (which also depends on vegetation and insect pressure). The tables developed to help selection (Volume IV) present the systems to propose in priority, according to agro-ecological zones and agronomic units. Identifying the agronomic unit and using these tables for the particular unit allow access to the range of technically feasible systems.

**Step 2. Definition of farmers’ objectives and priority crops** (for the farm as a whole, and to the particular plot)

**Step 3. Identification of available resources** at the farm level and that can be used on the particular plot: possibility to access inputs (and ability to bear the risk of such investment), available and mobilizable workforce, especially at critical moments (seeding, weeding, harvesting), technical ability of certain practices, off-farm activities, etc.
Step 4. Identification of agronomically possible systems that correspond to the farmer’s priorities, using the selection help tables for the particular agronomic unit. These tables present, for a particular unit, the possible systems according to the farmer’s objectives and resources (preferred crops, intensification/investment level, integration with livestock, etc.). At this stage we eliminate the systems that require methods incompatible with the possibilities of the farmer and those excluded at the terroir level (fady). On the other hand, we highlight those that allow particularly interesting results in economic terms, according to the opportunities of the market. As the economic interest of the different systems is extremely unstable, either due to time or space, it cannot be presented in this practical handbook and must be identified case by case (during the initial diagnosis).

Step 5. Presentation of possible systems to the farmer, by rapidly indicating the main advantages, and informing what are the possible/required levels of intensification and the expected revenues for the particular plot. The necessary resources (fertilizers, herbicides, pesticides and work force), that depend on plot conditions (weeds, initial fertility, etc.), must be presented in detail, along with the possible sequences of crop management to reduce certain requirements (mulching to reduce workforce and/or herbicide at weeding, for example). Therefore, this demands a study on the possible operational sequence for a given situation, which is the topic of Volume II. Chapter 2 of this handbook (detailed sequences of crop management per system are presented in Volume V). To understand this better, it is preferable to use the units commonly used by farmers (kapoaka, garaba, etc.).

- if the necessary resources are available and the farmer is ready to mobilize them, we present to him in detail, the benefits, constraints, risks (weather, fire, theft, etc.) and the capacity of the different proposed systems to recover after an accident (resilience). We show particularly the benefits and risks of intensive systems compared to systems with low-input requirements;

- as well, we present, the systems where the necessary resources are not available but can be obtained (possibility to access credit and necessary products, and risks bearable at the farm level);

- if the necessary resources are not available and cannot be obtained, if the minimum levels of inputs needed for the planned crop (of the particular plot) are too high, or if there is not a system possible to implement with the farmer’s priority crop in the particular plot (very low production, unprofitable and not allowing to «prime the pump» of direct seeding), it is necessary to change the priority objectives in order to adapt them to the available resources. Then, we return to step 4 that consists of the identification of the systems to propose with the help of the selection tables, for the particular agronomic units. Then two main options arise:

  - the priority objective remains the preferred crop production (usually rice), but its production may be delayed and the first objective becomes plot improvement for long term production (2 to 3 years) of the preferential crop;

  - the goal is to minimize risks (and therefore inputs) and to produce a less demanding crop, more appropriate to the available resources and to the plot fertility level. The ideal is to find systems that can meet both goals at once.
Once the solutions are identified, we present the respective advantages, risks and constraints of the proposed systems (particularly in terms of soil re-structuring and fertility improvement).

A third option may also be presented if the farmer is motivated to optimize the production of a specific crop, with available resources. In this case, we can propose the identification of a more appropriate plot to produce the chosen crop (by using the summary table of systems for the different agronomic units).

**Step 6. Selection of the cropping systems.** This selection is progressively advanced with the definition of a precise operational sequence for each selected system, which allows it to be driven on the particular plot, with the farmer’s resources, on his terroir. By eliminating the excessively restrictive systems and keeping only the most interesting, we retain only a few (maximum 4 or 5) well-targeted and well-argued propositions. The final decision about which system to choose for a given situation, is taken by the farmer who takes into account his objectives, constraints and assets. In order to allow the farmer to take an informed decision, the information necessary for this decision is provided to him (system’s cost and labour requirements, interest to invest in inputs, expected profit, risks, manageability etc.) via the summary table of the suitable systems, presented at the end of each agronomic unit, and on the descriptive sheets of systems per environment.

Depending on the situation and requests, additional procedures can/should also be adopted, such as:

- for a given agronomic unit, present the systems/crops made possible thanks to DMC, but which are impossible with traditional practices;
- for a particular constraint (plant pest such as Striga, risk of animals straying, compacted soils, etc.) present specific systems that might eradicate it.

These approaches and their combination enable farmers to make their choice not just at the plot scale, but at the farm and terroir scale.

However, we must recognize the limitations of DMC systems and let farmers know them, and feel free to refuse to support a farmer who would, against recommendations, grow plants under conditions that would not achieve good results. In these cases, it is very interesting to carry out a successful demonstration, by putting themselves in better conditions (input provision or growing other less demanding plants, for example).

But it is also possible to adapt the proposed systems to specifically meet the needs of farmers in specific situations. In fact, even if the proposed approach tries to be as close as possible to reality in the field, the number of systems presented in this handbook has been reduced to show only the main systems that may interest a large number of farmers. Consequently, systems that may be of great interest in specific situations are not presented here.

So, the summary tables and proposed systems do not wish to be obligatory “recipes” to be applied in every case. These summary tables should be considered as guides, presenting the general framework but can/should be adapted to real situations (by obviously respecting the principles of DMC systems presented in Volume I and II), within a global vision of the environments and systems. However, such an adaptation requires experience, a very good knowledge of usable plant material and good knowledge of all systems. Initially, it is recommended to limit oneself to the systems presented in Volume IV and V of this manual.
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Procedure to identify systems adapted to the requirements and constraints of farmers as a whole development plan, at *terroir* level

1. Identification of plot characteristics: agroecological zone, agronomic unit, constraints, etc.
2. Identification of farmer’s priority objectives (priority crop)
3. Identification des moyens disponibles et risques supportables

<table>
<thead>
<tr>
<th>Given plot x given crop</th>
<th>Proposable systems x resources necessary</th>
</tr>
</thead>
</table>

4. Possibilities to obtain the necessary resources (access to credit, bearable risks, etc.)
   - Search possibilities to improve plot (with available resources) to allow desired crop production in the long term
   - Search possible crops on plot with available resources
     - Given plot X Available resources
     - Possible crops
   - Identification of systems allowing the desired crop in long term on this agronomic unit with available resources
   - Identification of efficient crops and systems on this agronomic unit with available resources
   - Identification of the more favorable plots to achieve goals with limited resources
   - Presentation of possible crops and systems (interests, constraints and risks) with available resources

5. Presentation of possible systems, with their interests, constraints and risks
   - Use of descriptive sheets and summary tables with system characteristics
   - Use of tables to help on system selection for the particular agronomic unit
   - Use of summary tables with system characteristics
   - Presentation of possible systems (interests, constraints and risks) for priority crop on identified plots

6. Final choice of crops and systems on different agronomic units, taken by the farmer
5. Intervention at terroir level

The intervention at terroir level is not limited to plot or farm level. It must be done more generally, across all the environments observed and the various types of farms encountered.

5.1. Technical demonstration

Generally, the first actions on a terroir are done with the most innovative and motivated farmers, who are often listened to by the village community (opinion makers) and are conducted in a small part of their farm. The goal that extension workers must attain is to perform excellent demonstrations with these farmers, in diversified environments, using the most suitable cropping systems in these environments. These first plots should demonstrate to the whole village community how to enter into direct seeding mulch-based cropping systems rapidly.

5.2. Spatial arrangement of the territory

The intervention approach proposed for the dissemination of DMC systems can be applied individually according to the constraints and wishes of farmers, but it also aims to promote spatial arrangement activities on all agronomic units. It is thus possible to propose public activities in order to protect primarily the fragile areas, to develop grazing rangelands to limit animals straying, to make a community-based management of land or certain sensitive resources (such as biomass distribution between rice fields and tanety) when necessary, to control fire and/or install firewalls, etc.

5.3. Farmers’ associations and groups

Finally, the approach at terroir level must also target to encourage, promote, and stimulate the creation of farmers’ associations adept at direct seeding, in order to:
- facilitate exchanges between farmers (know-how, seeds, etc.);
- enable them to acquire the necessary resources for DMC practices (access to credit, sharing equipment or creation of service supply «per task» for specific operations such as seed treatment, etc.);
- optimize orders and reduce costs by combining input purchase;
- obtain better returns when commercializing production (routing and grouping sales, price information, product storage or processing), etc.

6. Some errors to avoid when choosing systems

A major step in the establishment of DMC systems is the choice of the most appropriate cropping systems for given conditions. In practice, during discussions with farmers to select crops and cover plants, it is important to avoid committing some errors:

6.1. Do not start by using excessively demanding plants

Very often, the plots proposed by farmers to implement new techniques are among the least productive ones. Nevertheless, the favourite crops are demanding crops (like rice). Fertilizer input on these plots/crops is generally risky and rarely profitable. So, during the first years we must absolutely avoid installing systems based on demanding plants, on soils which fertility cannot be raised to a level sufficient to ensure profitable production (grains and biomass), and that allows subsequent direct seeding under good conditions. Therefore, it is preferred to start with undemanding plants to «initiate» direct seeding in an efficient way, which will allow growing more demanding plants subsequently.
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6.2. Do not maintain a system when establishment delay renders it inefficient

The choice of systems is made in order to optimize biomass production in a given climate. This particularly requires that seeding is done as soon as possible. When establishment conditions cause a delay in seeding, it may be necessary to change the system. A long cycle crop installed too late under a climate with a limited production period might not complete its cycle, and produces low biomass. When the delay makes risk too high, we must choose a different system, associating shorter cycle plants, which will ensure grain and biomass production. This requires the ability to anticipate and react quickly.

6.3. Do not propose systems that require a risky investment

Some systems require an investment that can be substantial for a small family farm. These investments must always be safe. In the absence of safety (risk of theft, etc.) less intensive systems should be preferred, with less demanding plants. When security of tenure is not ensured, we must propose systems that enable a rapid return on investment (in the same year), such as cowpea on *Cynodon dactylon* living mulch, or cassava associated with brachiaria on degraded soils, which can double the yield of cassava compared to conventional practices, with a small investment.

6.4. Do not propose systems that require unavailable resources in the long term

Some cropping systems might be easy to establish, with very little resources, but require specific resources for subsequent re-cultivation. This is particularly the case of systems based on brachiaria, which is difficult to restart without herbicides. Before proposing such systems, it is necessary to make sure that the farmer will have the necessary resources at the moment of plot re-cultivation.

6.5. Do not propose systems that do not allow the maintenance of sufficient biomass

When the pressure on biomass is high, propose systems with palatable cover plants only if local rules and/or protection measures (fences, etc.) allow preserving a sufficient amount of biomass to «supply» DMC systems. Otherwise (straying, common grazing land, etc.), unpalatable plants must be used, like crotalaria.

6.6. Do not start with risky and/or complex systems

DMC practice requires training to obtain competence in these systems. So, it is better to start with very simple systems, easy to establish and to learn. During the early years, we must particularly avoid establishing plant associations which are difficult to manage, requiring a very good knowledge of plant material and a fine understanding of the operational sequence (herbicides, etc.), as well as very complex systems such as associating a large number of species.

7. Some examples of “robust” DMC systems

Among the wide range of DMC systems, simple systems emerge depending on the variability of the environment. They answer the main physical and socio-economic constraints of small farmers in the South, particularly through the use of minimal inputs (or even no chemical inputs), even in the most degraded soils, and integrate agriculture and livestock. Some of these systems can be applied generally, are universal in the tropics, simple to establish and to reproduce. They can be safely recommended in many situations.
7.1. Maize associated with twining legume

Associating maize with a twining legume (dolichos bean, cowpea, Vigna umbellata, etc.) is a particularly popular system among farmers for its many interests:

**Applicability**

These systems can be established in all the agroecological zones of Madagascar, and primarily in areas of average altitude. They are feasible without fertilizers on tanety’s «rich» or «moderately rich» soils, on baiboho, on soils in the plains which are not flood-prone, etc.

**Easiness of establishment**

Crop association management is easy, mainly by playing on the space between plants, seeding date, and fertilization.

Weed management is easy, because this type of crop association enables rapid soil cover. In addition, the possibility to choose the plant to associate allows a better adaptation to environmental conditions:

- cowpea is the plant that best supports high humidity conditions;
- dolichos bean, conversely, is the plant that best supports drought thanks to the power of its root system and ensures the highest biomass production during the dry season. It also provides the best soil cover with its woody stems which decompose more slowly than those of cowpea or Vigna umbellata;
- Vigna umbellata cannot bear a severe drought at the end of the rainy season (on tanety) but is the most resistant to insect attack.

Finally, re-cultivation is very easy, because these different species are annual plants, ending their cycle naturally and do not need to be controlled for the next crop seeding.

**Economic profitability**

This crop association allows the production of two crops in the same year, without affecting maize yield. These systems are very interesting economically, especially on rich soils where fertilizer is not essential. Moreover, the risks are limited in case of difficult weather conditions or insect attack (different sensitivity of the two plants to these stresses). Even in areas where locust attacks can happen, the legume provides production. Finally, this crop association can significantly reduce workforce cost (plot preparation and weed control in particular) thanks to high biomass production.

**Agricultural importance of crop associations**

These systems allow high production of aerial and root biomass (including during the dry season) and consequently are very efficient to prime the direct seeding «pump». Associating a cereal (with a fairly strong root system and a high C/N ratio) with a legume (nitrogen fixation, rapid decomposition), allows these systems to both enrich the soil (in nitrogen and organic matter, thanks to the diversity of inputs) and to restructure the soil. The long cycle legume also allows the mobilization of minerals during the dry season. The rapid decomposition of its leaves limits nitrogen blockage risk in the beginning of the next crop cycle. The next crop will benefit from a continuous supply of mineral elements, due to the different biomass quality provided by the previous crop association.

These systems are particularly very good as precedents for upland rice and cotton crops.
These crop associations may also be repeated year after year (crop rotation made possible by crop association that discontinues mono-cropping). However, it is recommended to alternate the associated legume in order to prevent the development of diseases, especially for cowpeas that can be strongly attacked.

In addition, rapid soil cover enables fast weed control (including Striga asiatica in the Mid-West and South-West) and erosion control. High biomass production ensures good plant cover, which allows cultivation during the following year without using herbicide, in most regions.

7.2. Intra-annual succession of rice/vetch in rice fields

**Applicability**
At medium and high altitudes, in all rice fields where the groundwater is accessible during the dry/fresh season, it is possible to grow vetch in the off-season, just after (or maybe a few weeks before) rice harvest. Vetch produces high biomass during the dry/fresh season, used to seed directly upland rice during the following season in very good conditions.

**Ease of establishment**
This system is extremely simple to establish and requires no knowledge or special equipment. The only constraint is the availability of vetch seeds.

**Economic profitability**
The economic interest in this system is its very low cost, largely compensated by the net gain of rice yield that succeeds it and benefits from the high input of nutrients (especially nitrogen) and weed control by vetch.

Agricultural importance of crop succession
The capacity of vetch to re-structure the soil (mainly at the surface, thanks to its roots and high biological activity), its strong capacity to fix nitrogen and ability to extract potash and phosphorus present in very low quantities in the soil, make vetch an excellent precedent for rice.

Vetch is able to dominate most weeds, including perennial weeds such as couch grass that would have been poorly controlled during the installation in year «zero». With its thick mulch, it leaves a very clean plot, allowing cultivation without herbicide during the next cycle.

In addition, it houses many arthropods and insect predators. In Madagascar, it greatly reduces *Heteronychus sp.* pressure and from other white grubs, a major constraint to rice cultivation in the highlands and at medium altitude.

To finish, vetch provides an excellent fodder, it is possible to partially export, and is a bee-friendly plant.
7.3. Systems based on *Stylosanthes guianensis*

**Applicability**

Below 1,500 m of altitude (although with slower growth between 1,200 m and 1,500 m), stylosanthes allows the development of particularly interesting systems on *tanety* and *baiboho*, and on certain rice fields. When established into cassava, it allows the renovation of degraded soils. When established in rice or maize, it can rapidly and sustainably increase production on moderately rich soils.

**Ease of establishment**

When stylosanthes establishes slowly, it represents very little competition to crops and therefore is very easily associated with rice, maize, cassava, etc. Depending on soil fertility, climate, priority crops and available space, it is possible to manage stylosanthes in a wide range of cycles, with variable intensity:

- alternating crop/stylosanthes (maize + stylosanthes // stylosanthes // rice + stylosanthes // stylosanthes, etc.);
- alternating two years of crop and a year of stylosanthes (rotation maize + stylosanthes // rice + stylosanthes // stylosanthes);
- every year crop associated with stylosanthes and prolonging its growth after harvest (rice + stylosanthes each year or rotation rice + stylosanthes // maize + stylosanthes in humid climate or on *baiboho*), etc.

Nitrogen fixation in substantial quantities by stylosanthes can significantly reduce fertilization needs by the following crops. Control can be performed manually (by simply peeling off with an *angady*), mechanically and/or chemically, which offers great management flexibility on all types of farms. Seed production is easy. It is seeded in small doses (2-6 kg/ha depending on seeding method) and can even be managed with a natural re-seeding.

**Economic profitability**

Systems based on stylosanthes are very inexpensive to implement and provide significant benefits thanks to the considerable production improvement. They also allow the enhancement of degraded land, abandoned by farmers (striga pressure, etc.).

**Agricultural importance of systems based on *Stylosanthes guianensis***

Stylosanthes (and consequently all the systems based on stylosanthes) has many interesting features, including:

- nitrogen fixation (70 to 200 kg N/ha), extraction of poorly soluble phosphorus, recycling bases and trace elements that benefit the following crops;
- production of high biomass, with variable quality: leaves and small roots with low C/N ratio, which decompose rapidly, and large roots and woody stems with high C/N ratio, which mineralize slowly and enrich the soil with organic matter;
- soil restructuring thanks to its powerful root system and its capacity to restart biological activity;
- total control of most weeds, especially striga, roettboelgia, borerria, etc.

Therefore, stylosanthes is an excellent precedent for many crops, especially for upland rice. To finish, stylosanthes is an excellent fodder and is also a bee-friendly plant. So, this is an ideal plant to manage under direct seeding mulch-based cropping systems, with minimal inputs, integrated with livestock and suitable for all types of agriculture in the tropics.