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2.3 PRODUCTION OF PRIMARY BIOMASS AND SEQUESTRATION OF CARBON WITH A HIGH WATER EFFICIENCY – THE COMPARATIVE ADVANTAGES OF DMC CROPPING SYSTEMS TECHNOLOGY

Francis Forest[1], Michel Raunet[2] and Bruno Lidon[3].
CIRAD, France.

[1] Head of Agroecology – DMC Unit , Cirad, TA 40/01 Ave. Agropolis, 34398 Montpellier CEDEX 5, France;
[2] Morphopedologist , DMC Unit Cirad – Montpellier
[3] Agronomist, watershed management specialist, Cirad.

Abstact

Whatever the cropping system adopted, bioclimatic conditions as sun radiation, temperature and rainfall, (spatial and temporal variability) are soundly affecting crop photosynthetic activity and biomass production. With the climate change already emerging in south east Asia (see El Nino impacts), there is a necessity for looking at new agricultural practices in the view of adaptation to
these new situations that farmers are going to face. This communication is dealing with the main agroclimatic and ecophysiological process that are involved in the biomass production in the case of the practice of no-till mulch based cropping systems DMC as already diffused with farmers by millions of ha in the world and beeing up to now under participative experimentation in south east Asia, mainly in Laos, Cambodia, Thailand and Vietnam in order to meet small farmers expectations. Main objective of this paper will be putting in evidence that sustaining high biomass production may be obtained by farmers through a fine tuned integrated management of the crop's biological microenvironment.

1 The primary biomass production basic model .

We may consider the basic equation 1 (Monteith,1972; Varlet-Grancher, 1982…) that is of great help to understand the process of biomass production as directly linked to the interception of radiation by the vegetal canopy with a ponderation through 3 efficiency coefficients : subfunctions :

$$\text{MS primary} = \int_{to}^{t1} Ec \,.\, Eb.\, Ea \,.\, RG\, dt \qquad \textit{équation 1}$$

- (1) Rg : Global radiation over the canopy during the cycle duration.
- (2) Ec : Climatic efficiency linked to bioclimatic conditions during the growing season
- (3) Eb : Photosynthetic Active Radiation PAR efficiency linked to crop's physiology (C3,C4)..
- (4) Ea : Efficiency ratio of useful component of PAR absorbed by the canopy directly linked to the leaf area index LAI. This efficiency is mainly affected by cultural practices and agronomic cropping system patterns.

Many experiments in agronomy had put in evidence the possibility of maximizing this global function by optimizing each of these 4 terms. According to on field's results obtained in Brasil, in Malagasy and in Cameroon, we may say that DMC technology by proposing a permanent biological and physiological activity for both aerial and subsoil plant's components is contributing to enhance the contribution of these 4 factors :

- Rg and Ec : maximizing the interception of sun radiation by a full diversified canopy during a maximum of time allowed by soil water availability. Soil water retention and sub-soil water regimes are so two important factors to guarantee a long growing season for main and cover crops.

- Eb , Ea : selecting the optimal combination of C4, C3 crops having a high LAI index allowing high daily AET[5] , mainly high transpiration resulting in high rooting system activity (cations pumping as described by L. Séguy and al, 2004), low water drainage and low loss of fertilizers.

Under finely managed DMC systems, production is finally resulting in enough biomass for having available both products for food and for mulch beeing transformed day by day in organic litter through enhanced soil biological activity. The crop's improved micro environment is so allowing all over the season a well balanced mineral nutrition of cover crops and main crops combined for producing high quality grain, fodder, fiber… Finally, these "service oriented " cover crops are able at recycling the maximal amount of primary biomass from various residues : empty panicle, leaves, shoots, roots that are left after main crop's harvesting.

2 Rainfall and biomass production

Under conventional tillage, due to significant run off and soil low water retention capacity, crop's production performances are frequently affected by both soil water stress and leaching conditions (see as an example alumine toxicity in ferralitic soils). This explains why rainfall is generally considered by farmers as a risky factor, cause of final biomass unpredictable variability.

As increasing the positive productive terms of the soil crop water balance (infiltration , transpiration, water storage..) and decreasing the negative ones (run off, soil evaporation..), DMC systems are considered as true alternatives in regions where temperature, rainfall are frequently aggressive as it is the situation in inter- tropical regions.

As DMC systems are significantly increasing soil water infiltration, cultivation of performant cover crops (brachiarria spp, stylosxanthes spp.) having a high rooting system activity for the extraction of nutriments in the deep soil is mandatory to avoid this risk of leaching. In humid situations, the fertilization strategy is also a key component for the successful adoption of DMC technology by farmers. In all cases, the estimation of two water balance terms, AET and Drainage, could be useful to compare the actual biomass production obtained by farmers and the expected yield (also called the agropedoclimatic potential). Analysis of the gap between actual and potential values may so be efficient to convince the farmer at changing of cropping patterns : change of planting date, crop cycle duration and obviously change in mineral fertilization strategy and monitoring.

[5] AET : actual evapotranspiration of crop wher the evaporative component is nearly nul under DMC

Yexp potential = Kfert x AETcycle x AETcp/PotMETcy *equation 2*

With :

- Kfert : coefficient linked to fertility and drainage
- AET cycle : actual evapotranspiration of crop linked to rainfall, soil humidity
- AETcp : actual evapotranspiration during the flowering critical phase
- PotMETcy : maximal evapotranspiration of the crop during the cycle

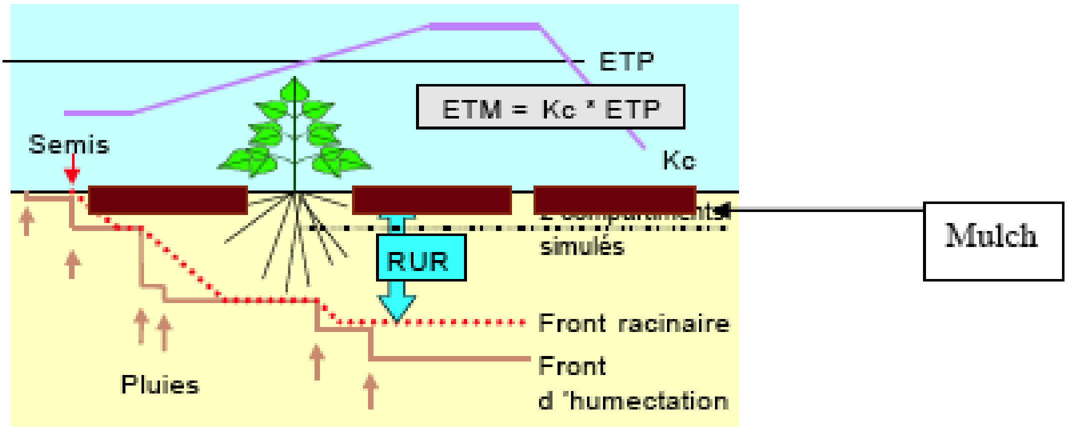


Figure 1 Main component of the soil crop water balance

To improve his cropping system, the farmer may so modify :

- The sowing period associated to the optimal cycle duration in order to capture the maximal amount of both global radiation and water. Many crops (as millet, corn, rice) are very sensitive to an early sowing date that finally is increasing the total Lai index.

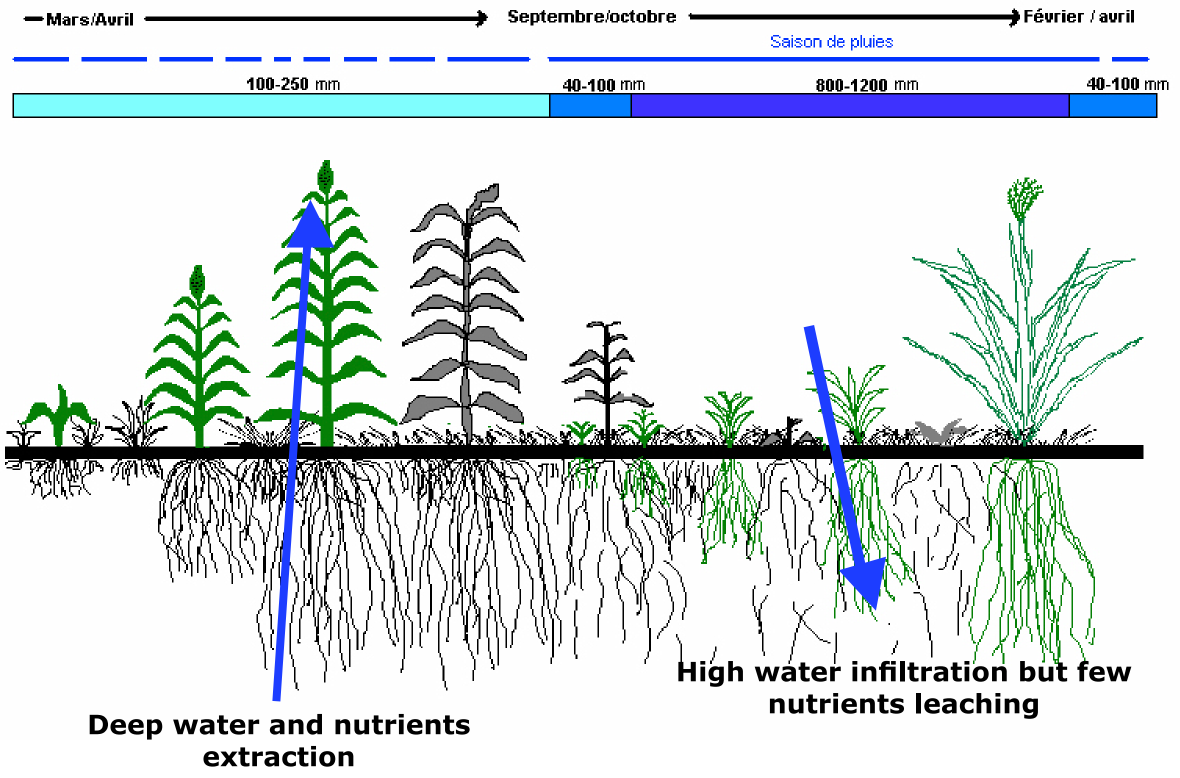
- As crop water demand is linked to Lai value, any input in mineral nitrogen will increase the crop water demand. In the case of conventional systems in low favourable climatic conditions, any reduction of the climatic risk may be obtained by reducing the crop density but with a negative impact on the expected total dry matter production.

- An other solution is to adjust (reduce) the nitrogen input during the early phase of the cycle in order to reduce Lai and AET with the objective of conservation of enough water in soil that will secure the crop if a drought period is coming (risk of crops burning). Compared to conventional systems, this adjustement is always efficient with DMC systems due to its ability at using organic N stored in the soil, especially if the rainfall distribution is finally becoming favourable.

- Finally, as DMC management is reducing run-off and bare soil evaporation (mulch effect), all these water balance oriented adjustements are resulting in an efficient increase of the crop 's transpiration productive flux. It is why, we may say that water balance in the case of DMCs systems may be defined as a good tool for estimating and predicting the productivity.

- Practically, the combination between the Monteih Energy model and the soil crop water balance model is used to estimate not only yield but also fertilizer use efficiency (kg grain /mm of rainfall /unit of fertilizer). This ratio is highly increased in DMC systems (fig 2) as permanent cover crops with powerfull rooting systems are avoiding both water loosing and leachning of nutrients.

Figure 2 Role of permanent cover crops on water and nutriments availability (Cerrados- Brasil)



As national action plans in Agroecology in Mekong Region have to propose strategies for the best use of soils and water resources, we may say that the DMC approach discussed in this paper, with the perspective at combining annual and perennial crops with a high efficiency for water and fertilizer, is an opportune alternative.

Therefore, looking at farmers constraints, on field DMCs solutions are not a panacea. If we may conclude that DMC technology is potentially an interesting option for both production and natural resource conservation : soil, water, biodiversity conservation, it is known from many experiences that the adoption process is very slow due to the complexity of sociological and economical constraints that are facing individual farmers.

On the agronomic point of view, we may see that DMC systems based on permanent biomass cover have the biophysical ability at producing more primary biomass, food, fodder with less inputs (rain , fertilizer , labour..) but only w thin a viability domain that is depending of many conditions and factors that are not generally under the control of farmers (education, availi-bility and access to inputs, quality of infrastructures..)

3 Long term impact : Organic matter and Carbon sequestration

If we consider a landscape's Unit combining annual, perennial crops, fields and plantations, these mixed agrosystems should combine productivity and sustainability by making the opti-mal use of the sun radiation and rainfall to produce a maximum quantity of biomass all over the seasons. The Henin equation 3 hereunder related to matter organic accumulation in soil aggregates is showing that the more we produce primary biomass and the most we recycle it on the surface layer, the more we increase organic matter and carbon accumulation in the soil.

$$C = C0 . e + k1 M (1 - e) / k2$$

$$\mathbf{DC/dt = k1\ M - K2*C = 0}$$

- C : Humus stock in the soil profile (1-10 cm)
- M : mean annual input of organic matter by the cropping system (in dry matter equivalent)
- k1 : Isohumic coefficient
- k2 : Humus related degradation coefficient
- C0 : Sustainability threshold

This equation is allowing at estimating a pertinent stability carbon treshold :

DC/dt = 0 or **M min = k2 * C / k1**

k1 and k2 values are measured in the field or estimated by using the relevant bibliography. In general, k1 is linked to the type of crop (C3 or C4) and k2 is dependant of soil micro environment (mainly temperature and oxydation rate).

As an example, values were measured in Brazil for annual cropping systems :

k1 = 0.26 for corn , sorghum residues.
k2 = 0.054 to 0.040 in conventional and minimum tillage in tropics
k2 = 0.010 in DMC no till mulch based cropping systems (Sà & al, 2007)

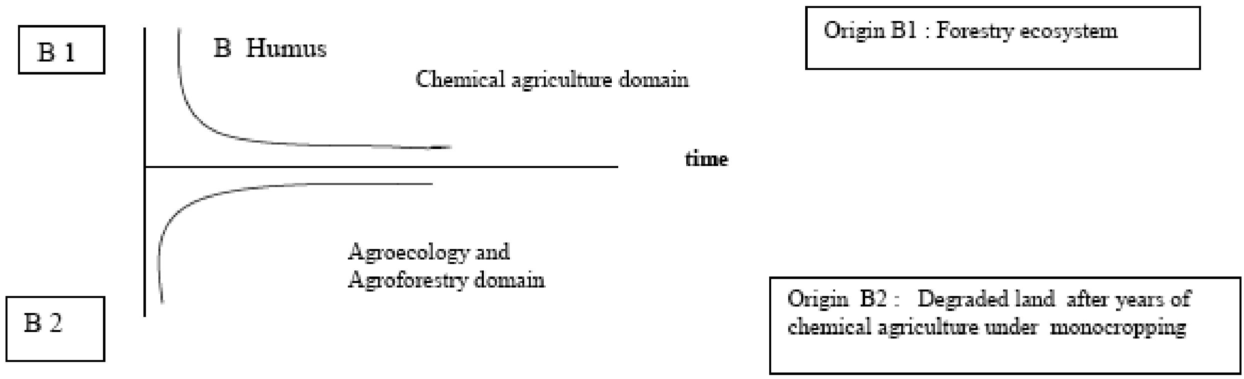


Figure 3 The Henin dynamic Model

4 Towards multifunctional DMC systems

Sustainability of an agrosystem may be analysed both on the productivity and on sustainability point of view by calculating the minimum amount of annual biomass input in soil Mmin needed to maintain this stability. Studies have shown that C storage is directly linked with C from crop residue input (Sá et al., 2001; Kong, et al., 2005; Séguy et al., 2006; Bernoux et al., 2006; Bayer et al., 2006).

C sequestration rates vary widely for the tropical zones (-0.03 to 1.7-Mg ha^{-1} yr^{-1}) and for sub-tropical zones (-0.07 to 1.4-Mg ha^{-1} yr^{-1}). On farm observed performances are generally below the potential of biomass production of those agroecozones mainly due to the fact that DMC recommendations are not fully applied (Corbeels et al. 2006; Bayer et al., 2006; Bernoux et al., 2006; Cerri et al., 2007).

Well managed DMC cropping systems with high biomass input to maintain the soil permanently covered can mimic the conditions founded in the natural vegetation (e.g. forest, savanna, etc…) and provide a continuous mass and energy flow releasing organic compounds to stimulate the soil biota biodiversity and the soil organic matter (SOM) changes (Uphoff et al., 2006; Six et al., 2006). This concept is based on the multifunctional action of each species in the cropping system interacting with the soil attributes and stimulating the biological activity in a systemic interdependence of the soil structure and the soil organic matter pools (Perry et al., 1992; Uphoff et al., 2006; Séguy et al., 2006).

Comparative results obtained by Sà and Séguy on DMC systems in Brazil and Malagasy are putting in evidence an ability for C sequestration depending of two main factors : i) total amount of carbon input during a long term sequence, ii) effect of type of soil management, crops and rotation.

Nevertheless, this organic matter accumulation is limited by the value of k2, that is directly linked to micro environments patterns (soil temperature and O^2 concentration). For this reason, it is necessary to create DMC systems that are able to reduce k2 value and to produce much biomass in order to assure a positive value to the DB/Dt differential function all over the crop growing season (as well this is the case of majority of natural agroforestry systems but that produce not much food !).

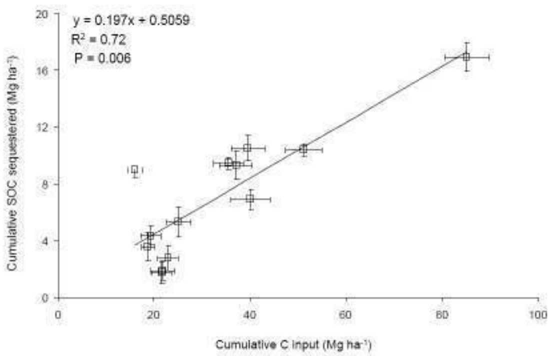


Figure 5 Carbon sequestration in DMC systems – Madagascar (10 years)
and Brazil (8 years) to be published (Sà, Séguy & al, 2008)

These results mean that DMC systems due to the permanent vegetal cover of soil (litter from trees, crops..) are the best option to sustain soil fertility with a minimal production of biomass. As an example, cumulative dry matter production observed over 10 years in a corn based DMC in Madagascar is nearly m = 50 Mg C $ha^{-1}yr^{-1}$ corresponding to a cumulative Carbon input of 20 Mg C $ha^{-1}yr^{-1}$ and finally transformed in 0.7 Mg C $ha^{-1}yr^{-1}$ organic carbon sequestrated.

A Carbon and Nitrogen survey implemented by Cirad and Embrapa (Corbeels and al, 2005) with a group of farmers in the Cerrados who have adopted the DMC system shows that soil C sequestration is in line with the 0.86 Mg C $ha^{-1}yr^{-1}$ (0-20 cm depth), estimated by de Sá et al. (2001) for DMC systems on oxisols in sub-tropical southern Brazil.

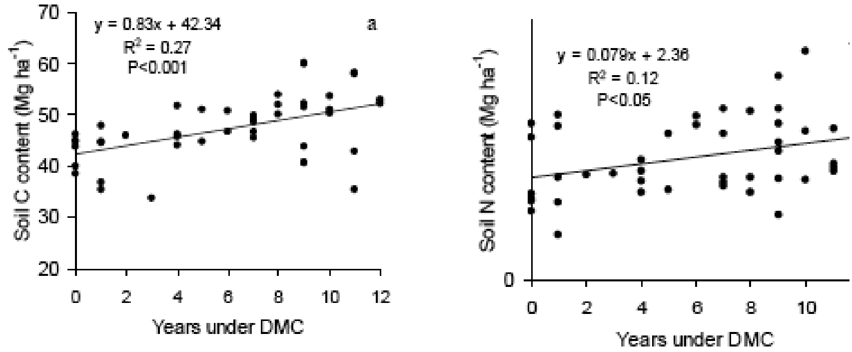


Figure 6. (a) Soil organic C and (b) total N contents in surface soils (0-20cm) in a DMC chronosequence in the Cerrado region of Brazil.

The comparison with the evolution of N content in soil shows that these 2 process are deeply linked. It means that a fine tuned Nitrogen monitoring in DMC systems by farmers is of high importance for chieving the expected high performances of these promissive systems.

This minimal amount of annual recycled biomass m to guarantee C sequestration is clearly not so easy to obtain (near 8 Mg C $ha^{-1}yr^{-1}$ in tropical areas). These DMC systems need to be performant stable annual N,P,K inputs without which they will be running as a mining process due to the high capacity for cover crops at extracting nutrients, cations from the sub soil. Therefore, if the
question of access to fertilizer is fully adressed, DMC practices for both annual and perennial cropping systems should allow the best efficiency of fertilizers (kg grain / unit of N,P,K) provided to the crops (Séguy et al, 2006).

5 Conclusion

After 8 years of on farm participative experimentations in the Mékong Région, we may say that DMC systems have the potential for improving both agricultural and livestock production.

Furthermore, they may also provide environmental regional national and global services if they are significantly adopted at a pertinent scale. Well selected watersheds within the Mékong Région, should now allow the pertinent monitoring of climate, soil , hydrological, agronomical as economical patterns we need for assessing with accurracy both short term agricultural performances and long term environmental and social impacts of this promissive technology.

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