Let us subsidize fertilizer for national food production in Sub-Saharan and Least Developed Countries to stabilize the climate and eradicate hunger.

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This paper has summaries for Policy Maker (SPM) in French and English (below), and 5 figures with bilingual caption, inserted between the two summaries and not repeated in the main text which is in english. A short bibliography is also given at the end of the SPM.

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Summary for Policy Maker.

Up to 2050, to meet future food demand of 9.5 billion people (twice as many as in the late 1980s,), crop yields are to be increased drastically, while preserving soils, forests and grasslands.

In 2015, U.N countries, with the different goals for sustainable development, did decide to eliminate hunger by 2030 and to preserve the climate. And with the Paris Agreement they agreed to maintain the mean global temperature since 1850, below +2°C, (+ 1.5 °C). According to climate models this would require global net GHG (greenhouse gas) emissions to be divided by 4 and to tend to zero after 2050. Simultaneously we should get adapted to climate changes, while meeting increased world food demand. This requires huge changes, not considered before the 3d IPCC report in 2001 that alerted countries about the necessity to decrease emissions both more rapidly and more deeply. This is an unprecedented challenge, unlikely to be met with present national policies and global population growth.

Tackling only the fossil energy sector will therefore be insufficient to meet UN objectives It would require leaving, until 2050, at least 2/3 of known fossil energy deposits in the ground, and at the same time meeting increasing energy services demands, through drastic improvements in energy efficiencies, strong increase of renewable energies (including modern bioenergy and bioproducts), and also with CCS (CO_2 capture from fossil fuel, which will still be used, and geological storage in the underground). The latter technique, already proposed in 1992, is however still experimental, and has costs ranging between $50 to $100 per ton of stored CO_2.

To produce enough food requires to considerably increase cereal yields, in particular in Sub-Saharan African countries (fig.1 above), where they have remained constant since the 1960s, at a very low level (close to 1 ton per ha), but where up to 2050 the population is about to double, e.g. to increase by more than one billion people. Fortunately yields can there still be easily improved by improving agricultural inputs per ha (more minerals and water input and improved seeds, more organic matter if it is available and can be transported). By raising mean annual input of fertilizer per hectare from about 10 kg as today, up to 50 kg, as recommended by the NEPAD since 2006 (IFDC 2006), total crop production could be doubled without needing further deforestation or conversion of grassland into cropland. At the same time minerals exported by crop harvesting could be replaced and thus avoid soil mineral depletion. Without such changes, African soils, already very phosphorus-poor, will continue to degrade. With 50 kg (fig.2), input would still be less than half of world average, only a quarter or a third of those in developed countries, in India and in Bangladesh, and six time less than in China. In China (Norse et al.2012) and other countries with high level of fertilizer input efforts, are

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to be made as recommended by FAO to use fertilizer more efficiently, e.g. using less while maintaining present crop yields. But in Sub-Saharan Africa and other Least Developed countries, fertilizer inputs are, on the contrary, to be increased. This is unfortunately too often ignored. In semi-arid regions, more water is also required for complementary irrigation (Diarra et Riedacker 2017).

To double crop production it is possible either to double cropland area or to double yields (Fig.3). Without such improvements the necessary doubling of food production in Africa will be obtained only by increasing cropland area, as between 1975 and 2000, during which period about 5 million hectares (half forests and half grassland) were converted annually (Eva et al. 2006). Land use change generates however 100 times more GHG emissions per ha (about 200 t of CO_2), than annual GHG emissions increase from inputs to double yields (only about + 2 t of CO_{2e} per ha, fig.4). In addition to that conversion into cropland, land use change also diminishes environmental services. To take appropriate decisions, to adapt to climate change, to combat parasites and to limit GHG emissions (Riedacker 20062008a and 2008b), it is therefore necessary to switch from the field to the landscape and then up to the world level. Higher global food demand will require for instance, either land use changes or increasing yields, or both types of changes, in one or several places in the world. This is shown in fig. 5.

In France, average wheat yields have been quadrupled between 1950 and 2000. This allowed [in comparison with a scenario with the same total production than in 2000, but with yields per ha as in 1950] to avoid the deforestation of 14.5 million hectares (about the total area of the French productive forest), and the emission of 4.5 billion tons of CO_2. It allowed also the preservation of the annual forest increment (110 million m^3, e.g. an annual net uptake of about 200 million tons of CO_2 from the atmosphere). Part of the annual wood increment is harvested annually; e.g. in 2016, 19 million m^3 as lumber, 10 million m^3 as wood for industry, and more than 8 million m^3 as wood for energy, (CTBA 2017) which together with industrial wood waste, firewood harvested outside forests, waste wood and paper, provided annually about 9 million toe (ton of oil equivalent) of primary renewable energy, (which could, by replacing petrol avoid the emission of more than 29 million tons of CO_2 , by assuming an average conversion efficiency of wood into heat of only half of that of fossil fuel). Increasing input have during the same period increased annual emissions by 9 million t of CO_{2e} since 1950, hence a net emission reduction of about 20 million tCO_{2e} per year.

Moreover, to produce as much wheat in France as in 2000, but with organic farming (with average yields reaching presently only 3,5 t of grain per ha, half of that of smart farming, Toquet et al. 2012), twice as much cropland, e.g. about 5 million additional hectares (of forestland of grassland), would be needed in France or elsewhere, to obtain the same total wheat production. This would be much less friendly both for the environment and the balance of trade! With lower input, as in Sub-Saharan Africa, this would even be worse.

This shows that priority should be given to increase the level of input per ha in Sub-Saharan African countries and other Least Developed Countries, both to adapt to climate change (including to increased climate variability), to improve food security and to limit increasing of GHG emissions.

How can this be achieved? This requires first of all adequate agricultural policies and measures (Boussard 2004). Almost all large entities of the world–subsidize heavily and in various ways their crop productions to maintain or increase yields per hectare. India and China subsidize fertilizer, Europe subsidized crop production on a per hectare basis (on average 271 € per ha, between 60 € and 600 €). When population is growing, and less fossil fuel is to be used, increasing yields becomes a necessity. To optimize crop production and avoid deforestation, input should therefore be subsidized everywhere in the world, to both combat climate change and improve national food security. Contrary to fossil fuel, for which it is desirable to remove subsidies as recommended by OECD economists, for renewable energies and crop production, (which is a particular form of renewable energy but much more land demanding) should be subsidized to improve solar energy and CO_2 conversion efficiencies of plants. This difference needs to become really acknowledged also by specialists of fossil fuel, which is today not often the case. If adding taxes on fossil fuel can be recommended, this is not the case for crop production input, which should, on the contrary, be subsidized even when consuming fossil fuel and emitting GHG emissions, at least as long this is acceptable for the local environment.

In developing countries, non-subsidized inputs (fertilizer, water etc.) are however generally not affordable by small farmers. Up to now only 8 African countries have significantly subsidized inputs to increase national food production. Commitments taken by Heads of African States, in Maputo in 2003, which recommended to spend 10% of national budgets for agriculture could not be respected (Wade & Niang 2014). This was a too big burden in their budgets. In the past in some African countries the cotton production allowed farmers to get fertilizer even in remote areas in exchange of part of their cotton production. They did use part of it for cotton production and another part for food crops. But high subsidies for US cotton producer, in addition to sometimes mismanagement in African countries have disturbed that system (Nubukpo 2011).

The international community should therefore become interested in helping to co-subsidize inputs in Sub-Saharan African countries and Least developed countries, not only out of charity, but also to protect the climate as a common good. Contrary to what some decision maker, donors and NGOs sometimes think, this is one of the least costly and most efficient action for climate change adaptation, climate mitigation and food security.

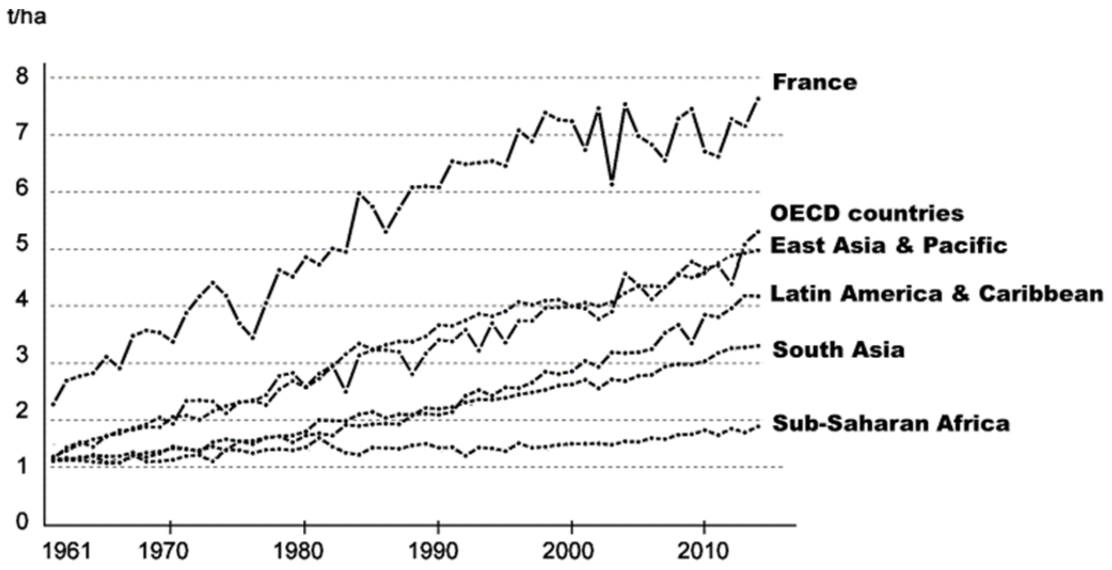

Fig. 1: Evolution of average cereal yield per ha in different regions of the world, between 1960–2014.

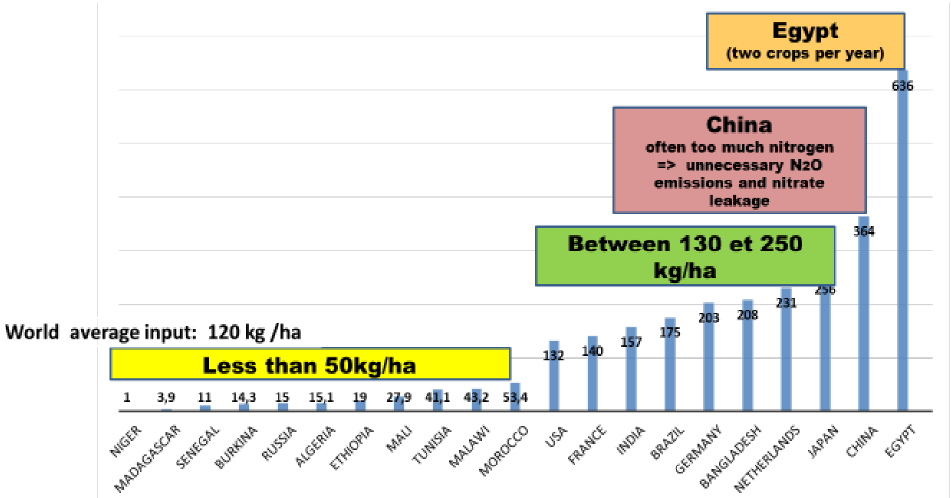

Fig.2: Average annual fertilizer consumption, in kg per ha of arable land, in some countries in 2013. *(World Bank data 2016)*

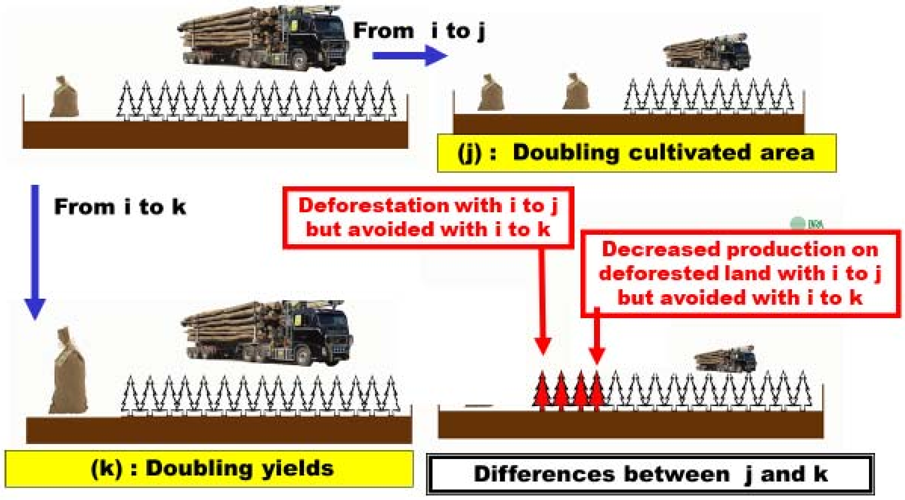

Fig. 3: To double food production it is possible, either to double dedicated cropland area without increasing yields (transition scenario from i to j), or to double yields on already cultivated land (from i to k). It is important to consider all changes: (1) GHG emissions resulting from land use change (e.g. deforestation as in this figure or conversion of grassland into cropland), (2) the decrease of previously harvestable products (wood as in this figure, or forage) on the land converted into cropland, which could replace fossil fuel or provide fodder, and (3) changes of GHG emissions on cultivated land. (Riedacker 2008 a & b)

An example: In Germany, without N fertilizer (the most energy consumer and GHG emitter of the fertilization) it is possible to get 9.4 t of biomass (grain and straw) per ha, whereas with 170 kg of nitrogen fertilizer input it is possible to get 16.4 t of biomass (+ 7 t of biomass). (from Küster & Lammers 1999). Assuming an emission of 11,7 t CO_2e per ton of urea (including manufacturing, transport and nitrous oxide emissions in the field), the average increase of GHG emission due to nitrogen input is about 2 tCO2e per ha. This annual additional emission can be compensated by converting efficiently less than 1 t of biomass into heat to replace petrol. Thus, an additional amount of 6 t of neutral GHG biomass can be obtained annually with the nitrogen fertilization. The additional biomass could also be partly or totally used as fodder

To produce the same amount of biomass without nitrogen input, 1,75 ha would be necessary (+0,75 ha). This land use change would generate an additional amount of GHG emission of about 234 t of CO_2 by deforestation, or 69 tCO_2 with grassland conversion into cropland.

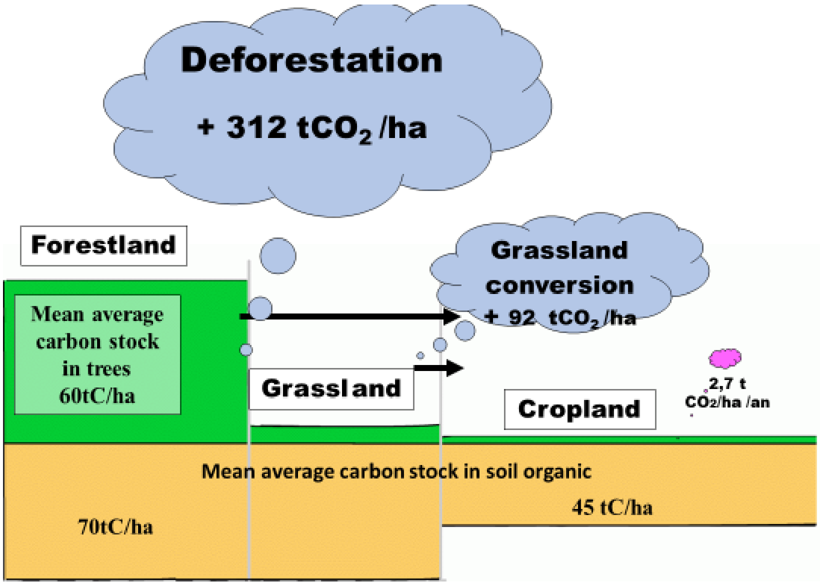

Fig. 4: **Average carbon stocks per hectare, in biomass and soil organic matter, in forests, grassland and cropland in France (Riedacker 2008a).** High yielding wheat fields in France emitted for instance annually in 2000 about 2.7 tCO_{2e} from fertilizer input (small bubble at the right-hand side), versus 0,7 tCO2e in 1950 but with yields four times lower than in 2000. Conversions of forestland and grassland into cropland generate respectively about 312 t of CO_2 and 92 t of CO_2 per ha, e.g. about 200 t of CO_2 per ha (with 1/2 forestland and 1/2 grassland). When only doubling yields, emissions from land use change are about 100 times higher than annual emission increase from fertilizer input. But as emissions from fertilizer take place year after year, whereas emissions from land use change are taking place at the very first year, adding fertilizer is therefore friendlier than land use change during about 2 centuries. In addition to that, as shown in fig. 3 above, avoiding land use change by increasing yields preserves wood/grass production and environmental services of avoided deforestation or avoided grassland conversion into cropland.

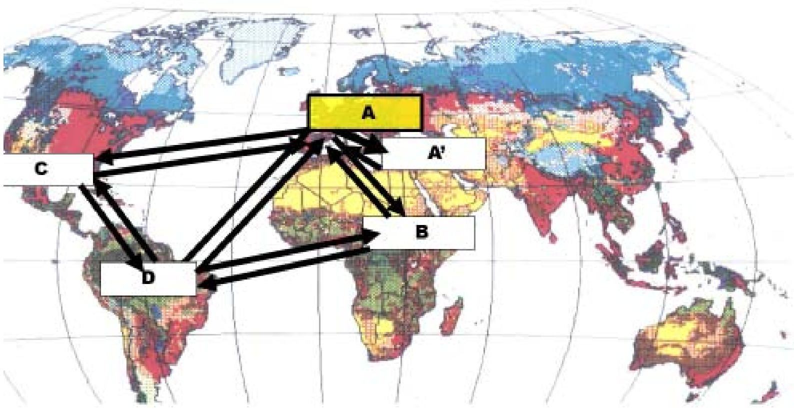

Fig. 5: **Effect of additional production of biomass or grain in the world**

When the total world biomass production is to increase, either for food or to replace fossil fuel, this can take place in one place (A) or several places (A' and/or B, and/or C and/or D). To limit as much as possible increasing net world GHG emissions from agricultural production, forest and grassland conversion into cropland should therefore be avoided as much as possible. This can be done by preferably by increasing, up to a certain point yields - and more generally land use efficiencies (annual production per ha of total land, by considering also fallow land, multiple and intercropping on the same total area) - in areas and countries where it is possible to increase yields with the least additional inputs, e.g. generally in countries where yields and inputs per ha are still low. For climate change mitigation it is necessary to assess changes at the world level and not only at the field or national level.

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