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

Subventionnons les engrais pour les productions alimentaires nationales dans les pays de l'Afrique subsaharienne et les pays les moins développés pour stabiliser le climat et éradiquer la faim.

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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.

Mots clefs supplémentaires : blé, céréales, efficacité territoriale, GES, atténuation du changement climatique, adaptation à la viabilité et au changement climatique, OMC.

Cet article présente des résumés pour décideurs (RPD), en français et en anglais, illustrés par 5 figures et des légendes bilingues (insérées entre les deux résumés), qui ne sont pas répétées dans le texte principal uniquement en anglais. Une brève bibliographie se trouve également à la fin des RPD.

Résumé pour décideurs

D'ici 2050 il faudra, sans défricher et tout en préservant les sols, augmenter fortement les productions alimentaires et non alimentaires afin de satisfaire les besoins mondiaux d'environ 9,5 milliards d'habitants, (deux fois plus qu'à la fin des années 1980). En 2015, avec les objectifs des Nations Unies pour 2030 pour le développement durable et l'Accord de Paris, les pays se sont engagés à éradiquer la faim d'ici 2030 et à stabiliser le climat d'ici 2050 à + 2°C, (+1,5°C) par rapport à 1850. D'après les modèles climatiques cela suppose de diviser les émissions mondiales nettes de GES (gaz à effet de serre) au moins par 4, puis de les faire tendre vers zéro après 2050. Il faudra donc réduire les émissions mondiales beaucoup plus rapidement et plus fortement que prévu avant le 3ème rapport du GIEC de 2001. Il faudra aussi s'adapter à ces changements, tout en satisfaisant les besoins alimentaires de tous. Voilà des défis impossibles à relever avec les croissances démographiques mondiales et les politiques nationales actuelles.

S'appuyer sur les seuls progrès réalisables dans le secteur des énergies fossiles ne suffira pas. Car il faudrait laisser au moins les 2/3 des ressources fossiles connues sous terre d'ici 2050, tout en satisfaisant les besoins énergétiques d'une population croissante : ce qui supposerait d'augmenter très fortement les efficacités énergétiques, de développer très rapidement les énergies renouvelables (y compris les bioénergies modernes, et les bioproduits), et aussi de recourir à la capture et au stockage géologique du CO_2 des énergies fossiles qui continueront à être utilisées. Cette dernière technique est connue et depuis 1992, mais elle est toujours expérimentale et réalisable seulement avec des coûts se situant entre $50 et $100 par tonne de CO_2 éliminée.

Pour produire suffisamment d'aliments il faudra aussi augmenter considérablement les rendements Des cultures vivrières en Afrique subsaharienne, où ils stagnent depuis les années 1960 (Fig. 1) alors que la population devrait y doubler d'ici 2050. Fort heureusement ces rendements peuvent y être encore facilement augmentés en accroissant les intrants (engrais, eau, semences et matières organiques si disponibles et transportables). En portant le niveau moyen des apports annuels d'engrais par hectare, actuellement seulement d'une dizaine de kg (fig.2), à 50 kg, comme le recommande le Nepad depuis 2006 (IFDC 2006), on pourrait y doubler les productions sans avoir besoin de défricher, tout en remplaçant les matières minérales des sols qui

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sont exportées des champs lors des récoltes. Sans ce changement les sols, déjà très pauvres en phosphore, continueront à s'y dégrader. Avec 50 kg on serait encore (à moins de la moitié des apports moyens mondiaux, à moins du tiers ou du quart de ceux des pays développés, de l'Inde et du Bangladesh, et à six fois moins qu'en Chine. Si, notamment en Chine (Norse et al.2012) et d'autre pays à hauts niveaux d'intrants des efforts doivent être réalisés, pour utiliser, comme le recommande la FAO, moins d'engrais tout en maintenant le niveau actuel des rendements par ha, en Afrique Sub-Saharienne il faut au contraire en apporter nettement plus qu'aujourd'hui. Cela est malheureusement très généralement méconnu. Dans les zones semi-arides il faut en outre apporter plus d'eau pour des irrigations complémentaires (Diarra et Riedacker 2017).

Sans l'adoption de ces mesures le doublement nécessaire de la production alimentaire (atteignable soit en doublant les rendements, soit en doublant les surfaces cultivées, Fig.3), ne sera obtenu qu'en continuant, comme entre 1975 et 2000, à défricher chaque année environ 5 millions d'hectares (1/2 de forêts et 1/2 de prairies), (Eva et al. 2006). Or ces défrichements moyens augmentent environ 100 fois plus les émissions de GES par ha que les apports d'engrais permettant d'y doubler les rendements (environ + 2 t de CO_{2e} par ha et par an, fig.4). Pour prendre les bonnes décisions il faut passer de la parcelle au paysage puis au niveau mondial (Fig. 5) (Riedacker 2006, 2008a et 2008b). Une augmentation des demandes alimentaires mondiales se traduit en effet nécessairement par des augmentations de rendements et/ou des changements d'utilisation des terres, en un ou plusieurs endroits du globe. C'est un aspect nouveau qu'on oublie trop souvent dans les raisonnements habituels où l'on ne considère trop souvent que les changements nationaux (cf. fig.3 et 5).

En France le quadruplement des rendements moyens en blé entre 1950 et 2000 a ainsi permis[par rapport à un scénario où la production totale aurait-été la même qu'en 2000, mais où les rendements seraient restés au niveau de 1950] d'éviter de défricher 14,5 millions d'hectares de forêts, d'éviter l'émission de 4,5 milliards de tonnes de CO_2 et de préserver l'accroissement annuel des forêts (110 millions de m^3 en 2016, correspondant à un prélèvement annuel net d'environ 200 millions de tonnes de CO_2 dans l'atmosphère). Une partie de cet accroissement est récoltée annuellement sous forme de bois d'œuvre (19 millions de m^3), de bois d'industrie (10 millions de m^3) et de bois énergie (au moins 8 millions de m^3), CTBA (2017), ce qui en fin de compte, avec les déchets, le bois récoltés hors forêts et les bois de rebuts, a permis d'‘obtenir de l'ordre de 9 millions de tep (tonnes d'équivalent pétrole) d'énergie primaire renouvelable et d'éviter l'émission d'environ 29 millions de tCO2e (en admettant un rendement moyen de conversion du bois et de la paille en chaleur égal à la moitié de celui du fioul). Les apports d'engrais ont, eux, augmenté les émissions annuelles de 9 millions de tCO_{2e} par rapport à 1950, d'où une réduction nette des émissions d'au moins 20 millions de tCO2e par an.

Par ailleurs, pour produire autant de blé en France qu'en 2000, avec moins d'intrants, par exemple avec l'agriculture biologique (produisant avec des apports d'intrants organiques actuellement, en moyenne, seulement 3,5 t de grain par ha, moitié moins qu'avec l'agriculture raisonnée, Toquet et al. (2012), il faudrait doubler les surfaces emblavées, donc défricher environ 5 millions d'hectares de forêts ou de prairies, en France ou ailleurs. Ce serait évidemment peu vertueux, tant pour l'environnement que pour la balance commerciale. Etant donné les bas niveaux d'intrants de l'Afrique Subsaharienne les résultats seraient pires encore.

Ces constats ont une évidente conséquence : il faut prioritairement augmenter le niveau des intrants en Afrique subsaharienne et dans les pays les moins avancés. Comment ? Tout d'abord en mettant en œuvre des politiques agricoles adéquates (Boussard 2004). Dans les faits tous les grands ensembles mondiaux subventionnent fortement leurs productions végétales, sous diverses formes : directement les engrais en Inde et en Chine, par des aides à l'hectare en Europe (en moyenne 271 € par ha, de 60 € à 600 €) etc. Quand la population augmente (et on ne peut évidemment pas la faire diminuer rapidement !) et quand il faut restreindre le recours aux énergies fossiles, il devient impératif d'augmenter les rendements des champs. Contrairement aux énergies fossiles, pour lesquelles l'OCDE recommande avec raison la suppression des subventions, quand il s'agit des énergies renouvelables, et en particulier des productions végétales, il faut au contraire apporter des soutiens pour augmenter les rendements des bioconversions de l'énergie solaire et du CO_2 par les plantes Il faudrait donc subventionner suffisamment les intrants, afin d'augmenter et d'optimiser les productions végétales, partout dans le monde, sans avoir besoin de défricher. Il est impératif que cette différence de traitement soit réellement comprise et prise en compte par les spécialistes des énergies fossiles. Si avec raison on envisage de taxer les énergies fossiles, il faut au contraire subventionner les intrants agricoles, y compris ceux consommant des énergies fossiles et émettant des gaz à effet de serres, comme les engrais azotés, tant que cela est admissible pour l'environnement local.

Dans les pays peu développés il importe de prendre en compte que les intrants (engrais, eau etc.) non subventionnés sont trop coûteux pour les petits agriculteurs. Et jusqu'ici seulement 8 pays africains ont, comme le Bangladesh, nettement augmenté leurs subventions pour les productions vivrières. Les engagements pris par les chefs d'états Africains, à Maputo en 2003, visant à consacrer 10% de leur budget à l'agriculture n'ont pu être tenu (Wade et Niang 2014). Cela pesait trop lourdement sur leurs budgets. Jadis, dans certains pays africains, l'organisation des filières de production de coton permettait de fournir des engrais aux petits agriculteur, même dans les endroits reculés, en échange d'une partie du coton. Ils épandaient alors une partie des engrais sur les champs de coton et une autre partie sur leurs cultures vivrières. Mais les subventions aux producteurs américaines de coton et les mauvaises gestions dans certains pays ont mis à mal certaines de ces filières (Nubukpo 2011).

La communauté internationale aurait donc intérêt à aider à co-subventionner les intrants pour les agriculteurs africains et ceux des pays les moins avancés, non seulement par charité et pour y accroitre la sécurité alimentaire, mais aussi pour le bien commun. Contrairement à ce que pensent certains décideurs, donateurs et ONG, cela aurait un effet bénéfique pour le climat et la sécurité alimentaire, tout en étant l'une des actions les moins coûteuses.

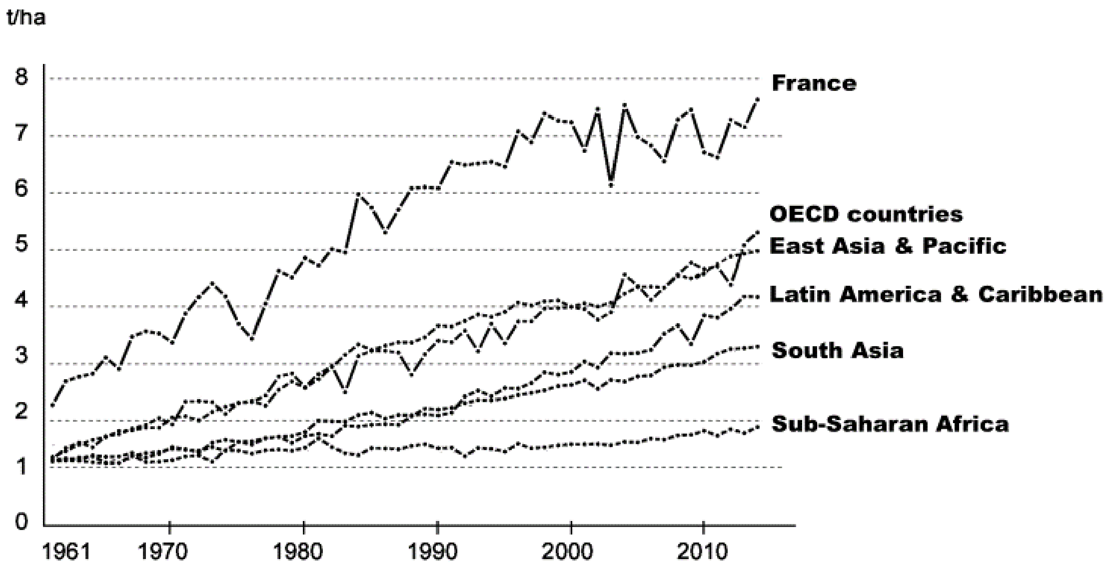

Fig. 1: Evolution of average cereal yield per ha in different regions of the world, between 1960–2014.
Evolution des rendements moyens par ha des céréales dans les différentes régions du monde, entre 1960 et 2005. (Worldbank data 20017)

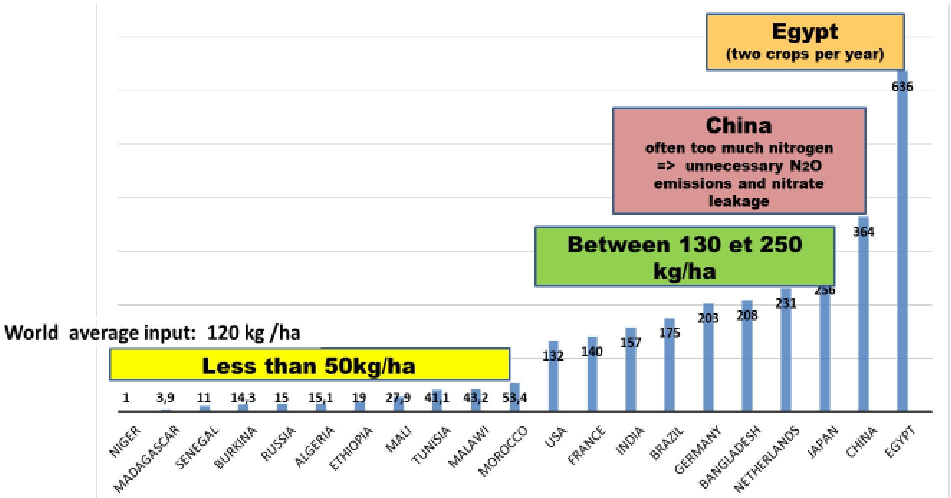

Fig.2: Average annual fertilizer consumption, in kg per ha of arable land, in some countries in 2013. ***Consommations annuelles d'engrais, en kg par ha de terres arables, en 2013, dans quelques pays*** *(World Bank data 2016)***)**

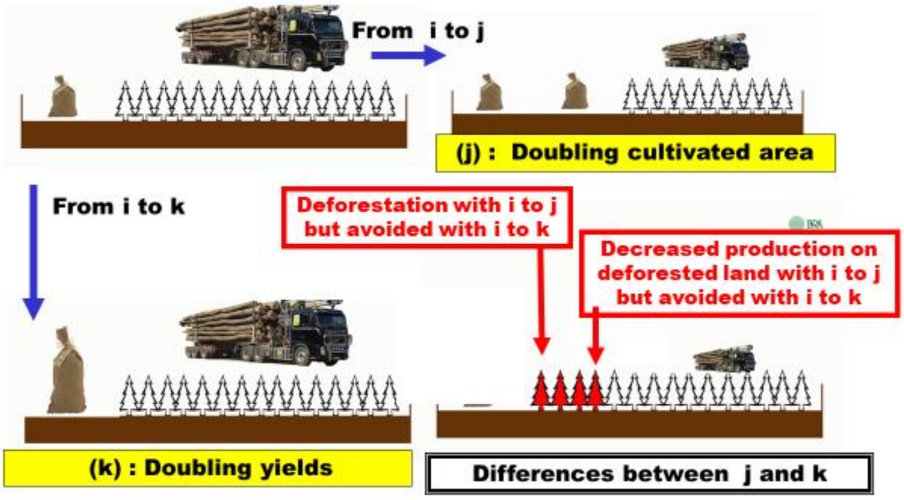

Fig. 3: To double food production it is possible, either to double dedicated cropland area without increasing yields (transition scenario from i to j), or to double yields on already cultivated land (from i to k). It is important to consider all changes: (1) GHG emissions resulting from land use change (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.

Pour doubler la production on peut, soit doubler la surface cultivée sans augmenter les rendements par hectare (scénario de transition de i vers j), soit doubler les rendements sans augmenter les surfaces cultivées (i vers k). Dans ces changements il faut prendre en compte tout à la fois (1) les émissions de GES résultant des réductions des stock de carbone résultant des changements d'utilisations des terres (du défrichement des forêts comme sur cette figure, ou de la mise en culture des prairies), (2) la diminution des produits auparavant récoltables sur la surface défriché (bois ou fourrage)e et qui pouvaient remplacer des énergies fossiles et (3) les émissions de GES sur les surface cultivées (Riedacker 2008 a et b)

A titre d'exemple : en Allemagne sans fertilisation azotée (la plus énergivore des cultures et la plus émettrice de GES) il est possible d'obtenir 9.4 t de biomasse (grain et paille) par ha, alors qu'avec 170 kg d'azote on peut obtenir 16.4 t de biomasse (+ 7 t de biomasse). (from Küster & Lammers 1999).

Avec une émission de 11,7 t CO_2e par tonne d'azote apportée sous forme d'urée) l'émission moyenne par ha (pour la production, le transport et le protoxyde d'azote au champ) augmente d'environ 2 tCO2e per ha. Cette émission annuelle supplémentaire peut être compensée en convertissant efficacement moins d'une tonne de biomasse en chaleur pour remplacer du pétrole. Il reste alors, à émissions totales de GES identiques, un surplus de 6 t de biomasse par an grâce à la fertilisation azotée Cette biomasse additionnelle peut aussi servir de fourrage.

Pour produire la même quantité de biomasse sans apports d'azote, il faut 1,75 ha (+0,75 ha). Ce changement d'utilisation des terres générerait un supplément 234 t de CO_2 en cas de déforestation et de 69 t de CO_2 en cas de mise en culture de prairies

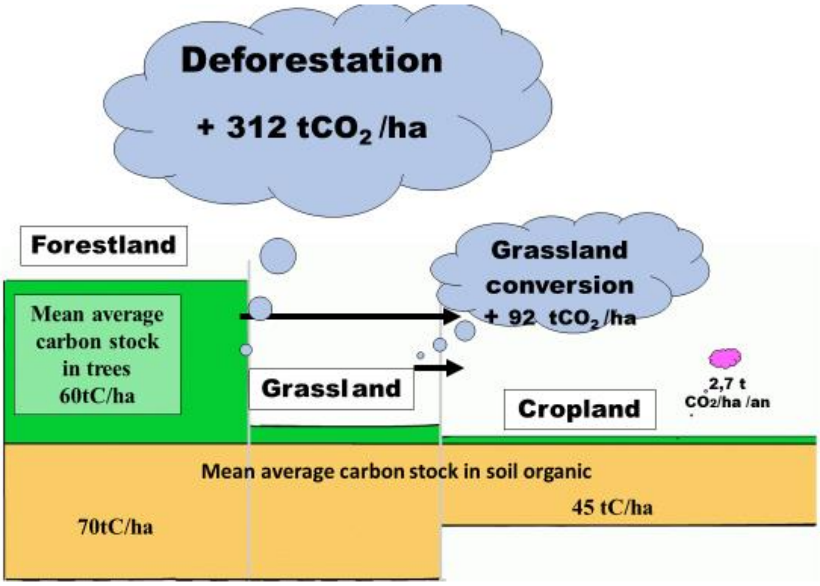

Fig. 4: **Average carbon stocks per hectare, in biomass and soil organic matter, in forests, grassland and cropland in France (Riedacker 2008a).** High yielding wheat fields in France emitted for instance annually in 2000 about 2.7 tCO_{2e} from fertilizer input (small bubble at the right-hand side), 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.

Stocks moyens de carbone par hectare dans les biomasses et dans la matière organique des sols, des forêts, des prairies et des cultures en France (Riedacker 2008 a). Les apports d'engrais de champs de blé bien fertilisés généraient environ 2,7 t de CO_{2e} par ha (petite bulle à droite) en 2000 contre 0,7 tCO2e en 1950, mais pour des rendements alors quatre fois moindre qu'en 2000. Un défrichement moyen, (½ de prairie et ½ de forêt) émet environ 200 t de CO_2, cent fois plus que l'augmentation de l'apport apport annuel d'engrais pour doubler les rendements. Mais comme les émissions des apports d'engrais ne se produisent qu'année après année, alors que celles des défrichements ont lieu dès la première année, il est plus avantageux pour le climat d'apporter des engrais au moins pendant deux siècles. Cela permet en outre de préserver la production de bois/fourrage et les services environnementaux des surfaces non défrichées (cf. Fig.3).

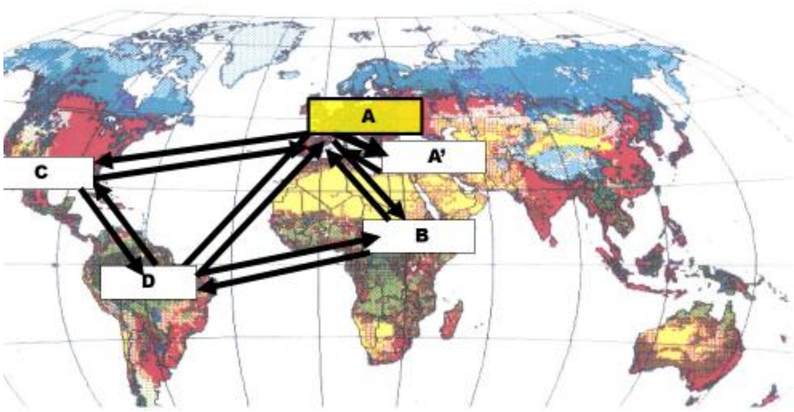

Fig. 5: **Effect of additional production of biomass or grain in the world**

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.

Effet d'une production additionnelle de biomasse ou de grain dans le monde.

Quand la production mondiale de biomasse doit augmenter pour produire plus de nourriture ou remplacer des énergies fossiles, on peut augmenter la production en un seul endroits, en A, ou en plusieurs endroits (A, A' et/ou B, et /ou en C, et /ou en D). Pour limiter autant que possible l'augmentation mondiale de émissions brutes de GES des cultures il faut éviter de défricher. C'est pourquoi il est préférable d'augmenter les rendements jusqu'à un certain point - et plus généralement l'efficacité territoriale (production annuelle totale par ha, en tenant compte également des superficies en jachères et des cultures multiples et/ou des intercultures) - là où ils sont les plus faciles à augmenter avec le moins d'intrants supplémentaires, donc en général dans les pays où les rendements et les intrants par hectare sont encore faibles. Pour l'atténuation du changement climatique il faut évaluer les changements au niveau mondial et non pas seulement au niveau du champ ou au niveau national.

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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 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.

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Main text

In December 2015 U.N. countries have agreed at the Climate Conference in Paris to maintain the mean global temperature increase between 1850 and 2050, below + 2° C, and possibly below + 1.5° C, and to improve food security. Previously in September of the same year they did adopt also 17 Sustainable Development Goals to, *by* 2030, "*end poverty, protect the planet and ensure prosperity for all, as part of the new sustainable development agenda*", amongst which, inter alia, goal 2 (Zero Hunger), and goal 13 (Climate Action). To comply with these commitments huge changes are to take place.

Climate mitigation: In 2015 humanity had already emitted about 2/3 of the GHG from fossil fuel that can still be emitted up to 2050, if we are to meet the climate mitigation target (IPCC 2013) of the Paris Agreement (UNFCCC 2015). *World net annual GHG emissions* should therefore be reduced at least by 15% up to 2020, be divided by 2 or 3 between 2020 and 2050, and be eliminated before the end of the century. But during this period least developed countries and many developing countries are expected to increase their per capita and national energy consumption. This means that developed countries are to reduce their emissions more drastically and rapidly than indicated above and that developing countries should also get developed by limiting as much as possible their net increase of GHG emissions. With the "National Commitments" declared by countries in 2017 to the UNFCCC, average global temperature is likely to be maintained only around +3°C, and this only if rich countries provide enough funds to achieve part of the commitments taken by developing countries. Commitments of all countries are therefore to be revised by 2020.

Food supply: At the same time the world population is likely to increase, up to 2050, by about 2.5 billion people. In Sub-Saharan Africa alone, where the average number of children per women is still very high (Canning et al., 2016), the population is expected to double and increase from 1 billion people in 2010, to 2.2 billion in 2050, e.g. to increase by more than one billion people! More food, especially in Africa, and non-food biomass is therefore to be produced, wherever possible in the world. And this, while limiting or avoiding at the same time GHG emissions which means limiting as much as possible forest and grassland conversions into cropland (IPCC 2000).

To meet these targets is therefore a completely new and huge challenge: This assumes that two third of easily extractible and known fossil fuel reserves should be left in the ground up to 2050! To avoid a drastic decrease of services per capita (in food supply, housing, industry, health, education, mobility), fossil fuel consumption is thus to be reduced drastically, both by using it more efficiently in all sectors, and by replacing part if it with more renewable energy, including renewable biomass. Concentrating efforts on reducing fossil fuel consumption, in developed and emerging countries, is therefore very important. But with the present low cost of fossil fuel, and to low carbon taxes, fossil fuel emission reductions are unlikely to be achieved at the rate and up to the level requested to stabilize the climate.

Similarly, avoiding conversion of forestland and grassland into cropland, while meeting the increasing demand of food and non-eatable biomass will also not be easy. In Africa, between 1975 and 2000, about 5 million hectares (about ½ forestland and ½ grassland) have been converted annually into cropland (Eva et all. 2006). This happened without intending to produce more biomass to replace fossil fuel. Assuming an average emission of 200 tCO_2 (ton of carbon dioxide) per hectare of converted land, this is likely to have generated annually about 1 billion ton of CO_2 (Riedacker 2008a). In some African countries, emissions per capita from land use change have been about twice as high as those from fossil fuel. (e.g. Togo National Communication to UNFCC, and Riedacker 2004). The FAO indicated similar average annual rates of deforestation in Africa between 1980 and 1995, but did not consider the conversion of grassland into cropland. In Latin America and South Est Asia much forest has also been converted to produce more exportable agricultural products (e.g. soy grain and palm oil).

If large reserves of fossil fuel are still accessible, much land is also available for future deforestations and grassland conversion into cropland; in 2000, out of about 4 billion hectares of land, only about 1.5 billion hectares were cultivated. When not considering global and local environmental services of forest and grassland, about 1 billion hectares in Sub-Saharan Africa, and the same area in Latin America, could still be converted into cropland (FAO 2003, Roudart 2010). Due to the expected population growth in Sub-Saharan Africa, the past trend of land conversion, associated GHG emissions are likely to remain unchanged, unless land is used much more efficiently, e.g. if fallow land area is reduced, and yields per hectare of already cultivated land are drastically increased. This is possible in Sub-Saharan countries.

Yields increased regularly since 1960 in most part of the World, except in Sub-Saharan Africa, were they remained stagnant at a very low level, around 1 t per ha (Fig. 1 above) whereas in many industrialized regions, and in some developing countries like China and India, cereal yields are however already high, and sometimes even close to the maximum achievable when considering local environmental constraints (FAO 2003).

- During 1950 and 2000 annual wheat grain production in France has for instance been raised from 7.8 million tons up to 35.4 million tons, without increasing the land area devoted to that production. As yields have been almost quadrupled, about 14.5 million hectares of land use change (about the total area of the French productive forest) have been avoided, (in comparison with a scenario with the same grain production in 2000, but where yields would have remained at the 1950 level). Emissions of respectively 2.9 billion tons of CO_2, (with ½ forestland and 1/2 grassland) avoided land use change, and 4.5 billion tons of CO_2 with avoided deforestation, could thus be avoided, just by maintaining average carbon stocks in biomass and soil organic matter in forests and grasslands. In addition to that, the annual biological increase of wood in the French forests *in 2016* [about 110 million m^3, corresponding to an annual net uptake of 55 million tons of carbon, or about 200 million tons of CO_2 from the atmosphere) could be maintained.

  Part of the annual wood increment could thus be harvested,

    -as lumber (19 million m^3 avoiding importing that quantity of wood from other countries or avoiding using less climate friendly building material),

    - as wood for industry (10 million m^3, for paper and cardboard production, which will still be needed despite the progressing digitalization),

    - as wood for energy (8 million m^3), (FCBA 2017)

    At the end, harvested wood for energy in the forests with waste wood and paper, provided about 9 million toe (ton of oil equivalent) of primary renewable energy, allowing to avoid - by replacing fossil oil (assuming an average conversion efficiency into heat only half of that of fossil fuel)- the emission of about 29 million tons of CO_2.

  In addition to that, local environmental services (soil protection, water regimes, biodiversity, etc.) could also be preserved (Riedacker 2008a).

In most countries, increase of food production has been obtained by increasing crop yields per ha: between 1950 and 2000 world cereal production raised from 650 million tons up to 1,900 million tons on almost a constant land area basis (660 million ha): 1.1 billion ha of land use change was thus avoided, due to increased land use efficiency (Borlaug 2006).

In many African developing countries and Least developed countries, (except in Bangladesh) cereal yields are today far from what could be technically achieved with the present scientific knowledge and without using GMO's (Riedacker et Adjahossou 2010). More recently, the FAO finally also stated that more food is to be produced without destroying forests (FAO 2016). With the too low financial support of agricultural inputs in most of these countries (except in Bangladesh), yields are still low, as shown above in fig.1 in the SPM above, and likely to remain low and sometimes to continue to decrease, due to the presently too low level of fertilizer input per ha frequent soil mineral depletion and therefore unsustainable agricultural practices (fig. 4 SPM). But agricultural inputs are more expensive than in developed countries, due to often higher transportation costs and lower national consumptions.

In this context bringing sufficiently rapidly down global CO_2 emissions from fossil fuel as well as from land use land use change, appears as a huge challenge, unlikely to be met only by tackling fossil fuel consumptions. In this paper we do however only consider policies and measure to produce more biomass, for food and non-food, globally and in each country, to meet increased food and biomass demand while avoiding at the same time further conversion of forestland and grassland into cropland.

In the first part, we consider the need to increase eatable (mainly cereals, but tuber need also fertilizer, and non-eatable biomass production per hectare of land in African and Least developed countries, by increasing inputs to increase yields of already cultivated land.

This can be achieved, while limiting increasing GHG emissions and coping with climate variability at national levels.

Why are national and global policies and measures not yet adequate to meet these objectives and what should be changed is discussed in the last part.

Together with the text below readers are invited also to consider fig. 1 to 5 in the Summary for Policy Maker above

I / The need to increase food production and agricultural input

According to the FAO (2009), world food production is to be increased by 70% in 2050. It was then suggested that this could be achieved with crop intensification (about 90%) and with increasing arable land by 120 million hectares. Kofi Annan (2007 & 2010), former UN General secretary, and after him also Jacques Diouf, former General Secretary of the FAO (Diouf 2010) called for a Green Revolution in Africa, primarily to allow this continent to escape from the poverty trap. Before them, Conway also called for a doubly Green revolution (Conway 1997). This supposes, inter alia, to give small scale farmers means to produce and sell their products. Many authors wrote that small scale farmers can use the land as efficiently as large-scale farmers (Petit 2011, Hazell 2014). But very often they do forget to indicate that this can be achieved only with adequate inputs (improved seeds, fertilizer, irrigation, etc.). Most African soils are for instance naturally to poor in phosphorus for good crop growth and yield (Pierri 1989). In western Kenya, as written in extension guides, soils have not adequate amounts of nitrogen and phosphorus. In some areas, soils also lack potassium. Fallow land with leguminous shrubs can enhance soil fertility, especially restore nitrogen and soil properties. But this cannot increase phosphorus content, because plants can only recycle what is available in the soil. It is therefore very often necessary to add phosphorus after the fallow period. (Amadalo et al. 2003). This has been known and shown for many years (IRAT 1968), and also shown through many IFDC experiments (Fig. 2 in SPM) and other African Research Centers (e.g. ICRAF, ICRISAT, African national research institutions and Universities. (Adjahossou et al. 2009).

In developed countries, due to breeding programs and increased and more efficient use fertilizer input per hectare, yields have almost tripled (FAO 2007). In 2002-03, world average annual input of fertilizer per ha reached about 93 kg: already 202 kg in East Asia, 175 kg in Western Europe, 146 kg in Asia, 102 kg in Asia and 90 kg in North America.

In some countries, e.g. in China and Vietnam, where average inputs per hectare of arable land are above 300 kg (Fig.6), fertilizer should be reduced and used more efficiently to avoid soil deterioration (for instance soil acidification which can of course be reduced by liming), nitrate leaching and unnecessary GHG (nitrous oxide) emissions.

On the other extremity, average input per hectare reached only 8 kg in Sub-Saharan Africa, 20 kg in Africa, 61 kg in South Africa, 69 kg in North Africa, and 80 kg in Eastern Europe (IFDC 2006).

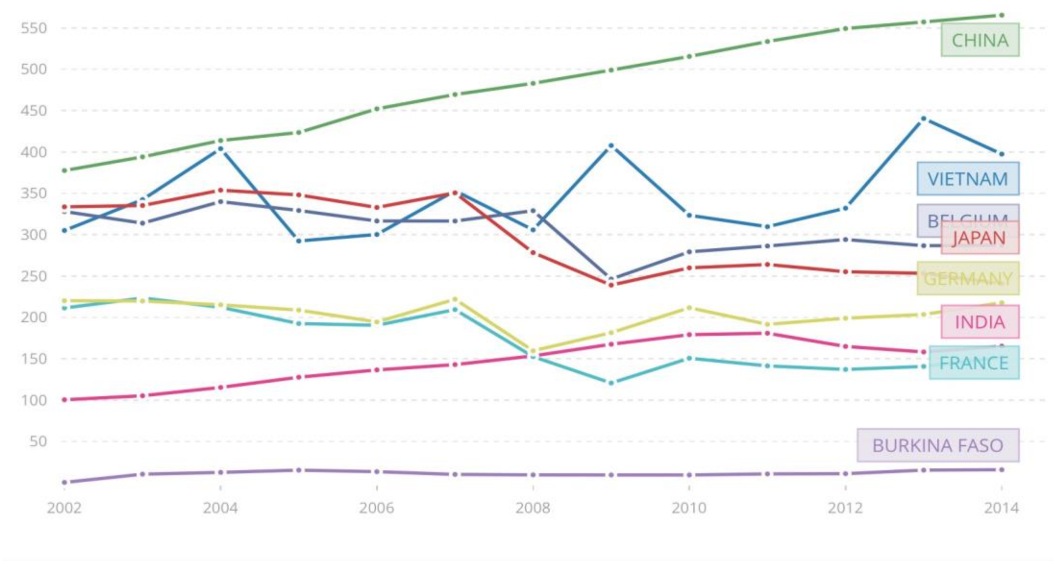

Fig. 6: Evolution of average input of fertilizer per hectare of arable land, between 2002 and 2014, in selected countries (China, Vietnam, Belgium, Japan, Germany India France and Burkina Faso).
Évolution du niveau moyen des apports d'engrais par hectare de terre arable, entre 2002 et 2014, dans quelques pays (Chine, Vietnam, Belgique, Japon, Allemagne, Inde, France et Burkina Faso). World-bank data (2017)

In 2006, at the Abuja International Conference of fertilization, the first objective of the final declaration was to raise the average annual input of fertilizer per hectare, from less than 10 kg, to at least 50 kg by 2015. (IFDC 2006). If some countries have increased a little bit their fertilizer input between 2003 and 2013, in most Sub-Saharan African countries, they were still very low in 2013, and far from the objective of 50 kg per ha and per year (Fig.2 in SPM). Except in Malawi where fertilizer input reached 43 kg per ha, which is close to what was recommended in 2006. With the 2006 NEPAD recommendation (50 kg per ha), average input would still have been less than half of average world input in 2013, 3 to 4 times less than in most in industrialized countries (e.g. U.S., France Germany, Netherland) and in some developing countries (e.g. India, Brazil and Bangladesh), 5 times less than in China and about 20 time less than in Egypt! Egypt appears as an exception. Due to its limited amount of arable land, most of the cropland is irrigated with the Nile water and bears now almost two crops per year! Cereal yield per ha are today comparable to those of Europe (Blanc 2002). But due to the large population increase since the beginning of the 20th century, this country is still to import large quantities of wheat every year.
In India fertilizer input per ha and food grain production has regularly increased since 1969 (Fig.7). This was a necessity as almost no land is available for further cropland expansion. The net sown area could increase only from 133 million hectares in 1960 to 142 million hectares in 1995, whereas the land-man ratio decreased from 0.32 ha to 0,19 ha (Gupta 1999). Due to the inelastic land supply in this country, large efforts are still made for further adoption of fertilizer (Shah 2009).

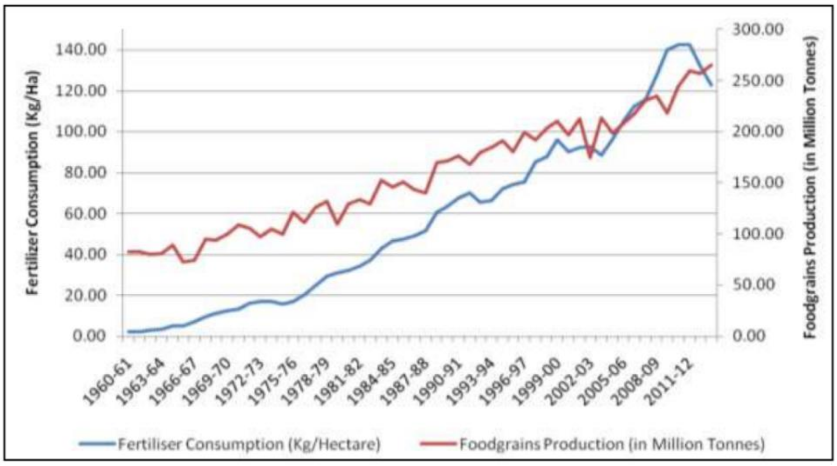

Fig. 7: Evolution of fertilizer consumption per hectare and total food grain production in India, between 1960 and 2012 (Evolution de la consommation d'engrais par hectare et de la production de grain (en millions de tonnes), en Inde, entre 1960 et 2000 (Chart 8, from Gulati and Banerjee 2015) .

In most countries, increase of food production has been obtained by increasing crop yields per ha: between 1950 and 2000 world cereal production raised from 650 million tons up to 1,900 million tons on almost a constant land area basis (660 million ha): 1.1 billion ha of land use change was thus avoided, due to increased land use efficiency (Borlaug 2006).
But in most Sub-Saharan African countries increased food production has been achieved by increasing cropland area. Fig.8 shows the difference between South Asia and Sub-Saharan Africa.

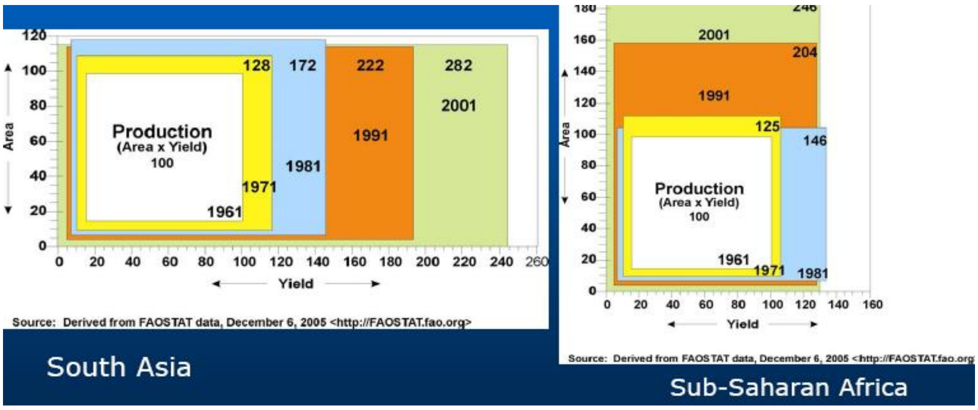

Fig. 8: Two ways of increasing Food production: (1) by increasing primarily yield such as in South Asia and (2) by increasing primarily cropland area, as in Sub-Saharan Africa.

Deux manières d'accroître la production alimentaire : (1) augmenter principalement les rendements par hectare, comme en Asie du Sud ou (2) augmenter principalement la surface cultivée, comme en Afrique sub-saharienne **(**from the IFDC Conference 2006)

II/ Increasing food and other biomass production, while limiting increasing GHG emissions.

In fig.3 of the SPM are indicated the different changes to be considered, when total food production is to be increased, for instance to be doubled, as in Sub-Saharan Africa up to 2050: (1) land use change (with i to j), e.g. deforestation or conversion of grassland into cropland), (2) avoided decrease of wood (grass) production due to avoided land use change (with i to k), (3) GHG emission on k and on j which is twice that of k.

After the first IPCC conference in 1990, at Sundsvall in Sweden, which led to the start of the negotiations of a Climate Convention in 1991, IPCC already recommended to avoid deforestation to limit CO_2 emissions from land use change (Riedacker 1991, IPCC 1992, IPCC 2000)
At that time, we knew already that GHG emissions per hectare from phosphorus and potassium inputs to increase yields of already cultivated land were low, compared to emissions per hectare of deforested land. (Riedacker et Dessus 1992). But it was impossible to estimate precisely the real net average contribution nitrous oxides (N_2O) emissions from nitrogen input (from manure or mineral fertilizer) used to increase yields. This was important, as nitrous oxide derived from these inputs has a GWP (Global Warming Potential) per kg of gas, about 300 times higher than that of CO_2. IPCC N_2O emission factors became available only after 2000; on the *average* about 1,25 % of N input was then considered to be transformed into N_2O. In the 2006 revised IPCC Guidelines, the average emission factor of N input was brought down to 1%, but with N emissions varying between 0,3% à 3,95% of N inputs (IPCC 2006). We could then compare more precisely the effect on net GHG emissions of increasing input to increase yields, with average land use change. (Riedacker 2006, 2008a 2008b, 2015). Fig. 4 in SPM shows average carbon stocks in forest biomass, and soil organic matter of forests, grassland and cropland and GHG emissions of high yielding wheat fields in France in 2000 (annually a little less than 3 tCO_2e (ton of CO_2 equivalent) per ha for 7.4 t of grain, Riedacker 2008) and only about 2 t of CO_{2e} from fertilizer, when only doubling yields.

Calculations of average CO_2 emissions can be made in each country by using *mean* average carbon stocks in forests, grassland and soil organic matter. Under the tropics carbon stocks in biomass may for instance reach, instead of 60 t of C per hectare as in temperate forests, up to 185 t of C in virgin Amazon forests (and emit about 678 tCO2 per ha when converted into cropland), 125 t of C per ha in sustainably managed forests and less than 65 t of C per ha in degraded forests about to be converted into grassland and then eventually into soy cropland.

The calculation above, and fig. 9 below, show that when crop production is to be increased and GHG emissions to be limited, it is preferable first to try to increase land use efficiency (e.g. by using a little more fossil fuel embedded in fertilizer) rather than increasing cropland area by converting forests or grassland into crop land. This allows also to preserve forest production and local environmental services as already mentioned.
In most African countries, yields can also be increased by using improved seeds and a reasonable amount of fertilizer (Fig. 9)

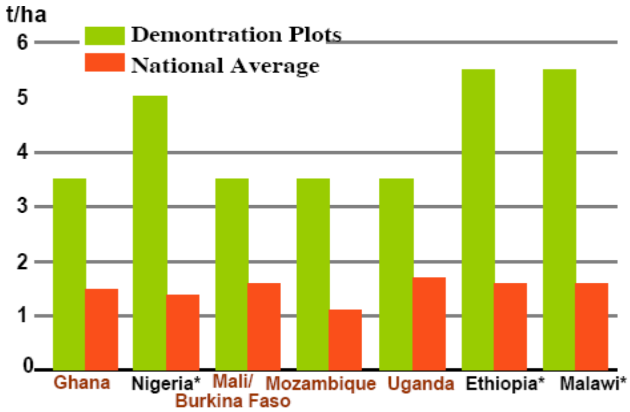

Fig.9: Yield of maize in demonstration plots and national average yields in several African countries before 2005. ***Rendements en maïs dans les parcelles expérimentales (en clair) et rendements moyens dans plusieurs pays africains avant 2005.*** (IFDC 2006)

In Benin, with just improved seeds, average maize yields can be raised from 1t per ha to 1.5 t per ha (Benin National communication to UNFCC). But by using also a reasonable amount of fertilizer (100 kg of 10-20-20 per ha) maize yields mays reach up to 4.7 t ton of grain per ha. And by intercropping maize and peanut, land use efficiency (total annual production of biomass, or calories and proteins, per hectare) can be further increased. The territorial intensity of the annual diet per capita may thus come down from 0,21 ha, for the traditional system with neither improved seeds nor fertilizer, to 0.05 ha per capita with improved seeds fertilizer and intercropping with peanuts (Adjahossou et al. 2009). Considering the present population growth in Benin, with the latter system this would avoid up to 2050, the deforestation of 2.7 million ha. And annual GHG emissions for food production would thus increase only by 53 million tons of CO_2, instead of 945 million tons of CO_2 with unchanged traditional practices. Despite the use of more fertilizer this would avoid the emission of about 842 million tons of CO_2 between 2010 and 2050 (Oïkos-Ceforid 2015).

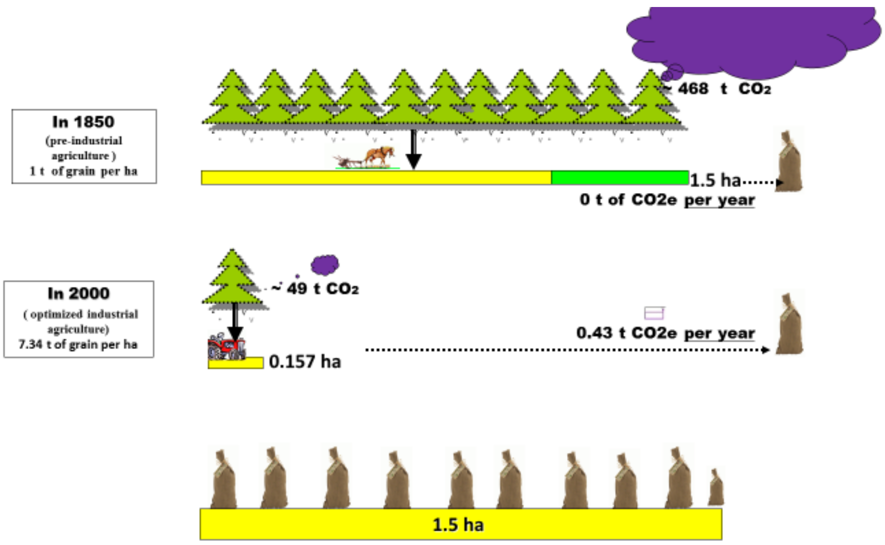

Fig. 10: GHG emissions in France, per additional ton of grain in France in 1850 and 2000

- **above, a 1850 pre-industrial agricultural system, with triennial crop rotation and an average yield of 1 t per ha, needing 1.5 ha per ton of grain when taking into account the fallow land[2]**
- **in the middle, a 2000 optimized industrial agricultural system, where only 0.157 ha are needed per ton of grain.**

[2] With a biennial crop rotation system, as during the 17th century, with 1 t per ha, 2 ha were necessary to get one ton of grain.

- **below, the amount of grain (9.5 t) which can be produced in 2000 on 1.5 ha, on which only 1 t of grain could be produced in 1850** (adapted from Riedacker 2008
- **GHG emissions per <u>additional</u> ton of grain were considerably higher in 1850 (+468 t of CO_2 per additional ton of grain, due to the large are needed per ton of grain, and only 49 t of CO_2, but once, due deforestation of only 0,157 ha and 0,42 t of CO_{2e} emissions annually per ton of grain resulting from fossil fuel consumption embedded in fertilizer and for tractors, and from nitrous oxide emissions from nitrogen input. Additional impact of 2000 GHG emissions per additional ton of grain is therefore more climate friendly during almost 20 centuries (when considering the temporality of GHG emissions from cultivation) than an additional ton of grain with pre-industrial agricultural practices which still exist in some Sub-Saharan African countries**

Emissions de GES en France, par tonne de grain supplémentaire en 1850 et en 2000.

- en haut, en 1850, avec des systèmes de culture préindustriels, des rotations triennales et un rendement moyen en blé d'une tonne par hectare, il faut, quand on considère aussi les surfaces en jachères, 1,5 ha par tonne de grain ;
- au milieu en 2000, avec un système agricole industriel optimisé, la surface nécessaire par tonne de grain n'est plus que de 0,157 ha ;
- en bas est représentées la quantité de grains (9,5t) que l'on peut produire annuellement en 2000 sur la superficie où l'on ne pouvait obtenir qu'une tonne en 1850.

Les émissions de GES par tonne supplémentaire de grain s'élevaient, par suite du défrichement, à +468 t de CO_2 en 1850 contre seulement, en 2000, 49 t de CO_2 pour le défrichement et 0,42 t de CO2e par an pour les émissions de GES provenant de l'énergie incorporée dans les engrais et les carburants utilisées et des émissions de protoxyde au champ. En tenant compte de la temporalité des émissions résultant des cultures, l'impact additionnel sur le climat d'une tonne supplémentaire de grain en 2000 est moindre durant 20 siècles que celui d'une tonne supplémentaire en 1850, ou avec des pratiques existant encore dans certaines régions de l'Afrique sub-saharienne

By considering also coproducts, e.g. additional production of harvestable straw, net emissions per additional annual ton of grain in 2000 can become negative: due to the extra amount of straw (+ 4.2 ton of straw per ha or 0.6 t of harvestable straw per ton of grain, which represents a potentially net GHG emission reduction of about 0,78 ton of CO_2). Annual emissions from grain production can thus potentially be compensated by converting part of the harvestable straw into heat to replace petrol; this straw can also provide, if not converted into energy, 0.83 FU (Fodder Unit) per ton of dry straw.
With decreasing land use efficiency, more land will be necessary, when the same amount of grain is to be produced *(e.g. fig.4 of the SPM, with scenario from k to j)*

But at farmer’s level, due to unfavorable- too erratic or too low- precipitations, fertilizer input may not be economically attractive during low years with insufficient rainfall. Where this risk does exist, especially in semi-arid zones, it is necessary to also improve water supply for irrigation or complementary irrigation: with dams, small dams, or hill reservoirs as in North Africa and in the Middle East, where it is raining during winter time (Blanc 2002, Albergal et al. 2004); with dams, small scale 200 m^3 reservoirs in front of 0,2 ha of cropland areas with rainfall water harvesting, water pumping etc. as in Sub-Saharan Sahelian countries, where it is raining in summer time Diarra et al. 2016 and Diarra & Riedacker 2017).(Fig. 11)

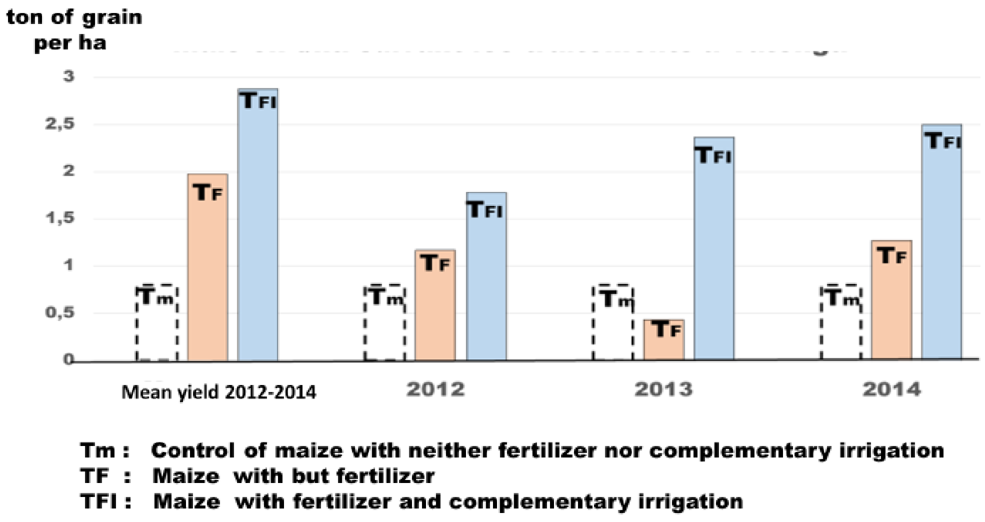

Fig. 11: <u>More crop per drop of water</u> : Average yields, in North of Burkina Faso under semi-arid conditions, of control plots (Tm), of corn fields, neither fertilized nor irrigated (0.8 t of corn per ha) , of (TF) but fertilized fields (155 units of NPK) without complementary irrigation (about 2t per ha but quite irregular yields) and of (TFI) fertilized fields with complementary irrigation from harvested rain, stored in 200 m3 ponds (2,9 t of grain per ha, with more regular yields). (Diarra et al. 2016, Diarra et Riedacker 2017).
*<u>Plus de production par mm d'eau</u> : Rendements moyens, au nord du Burkina Faso, en région semi-aride, de parcelles de maïs (Tm) non irriguées et non fertilisées, (0,8 t de grain par ha), de parcelles (TF)seulement fertilisées (*155 unités de NPK*) et non irriguées, (environ 2t de grain par ha), et de parcelles (TFI) fertilisées recevant de l'irrigation complémentaire avec de l'eau de pluie récoltée et stockée en bassins de 200 m3. (2,9 t de grain par ha, avec plus de régularité) Diarra et al. 2016, Diarra et Riedacker 2017).*

Africa has the potential to irrigate 20% of its arable land, but only 4% was irrigated in 2006 (IFDC 2006).

According to Norman Borlaugh, the Nobel Laureate, quoted by Gupta (1999), *but for the use of chemical fertilizers, India and China would have needed about 2-3 times more land under cereal to meet the food need of 1991, if they had continued to use the technology of 1960, and not increased the food productivity to sustain its present level of food grains production".* At that time, very few people were concerned by climate change. Today we can make the same statement, not only for some developing countries, but also for industrialized countries (as mentioned above for France): they use comparable quantities of fertilizer per hectare to maintain high land use efficiencies, to avoid land use change. This allows them also to limit the increase of GHG emissions, and to adapt their agriculture to future climate change.
At the global level, additional land that may become available up to 2050 for afforestation and biofuel production depends very much on changes in land use efficiencies. Based on the four IPCC contrasted SRESS scenarios, Dameron et al. (2005) found that with a market driven economy only 0.14 million ha may become available, whereas with a more environmental and social approach up to 0.94 million ha could become available.

This is just an overview to explain in a simple way this issue also to non-specialized readers. We are also to draw attention here, upon the fact that very often comparisons are still made without considering the whole land use and avoided emissions resulting from using fertilizer, due to reduced land use change when food and biomass production are to be increased. Low input farming can then be presented, but misleadingly, as the best option to reduce GHG emissions. To make adequate comparisons not only average changes in the whole landscape (including fallow land and multiple cropping) are to be considered, but emissions are also to be expressed per ton of product, and not only per hectare. The fact that more land is necessary when food production is to be increased, is a major difference with fossil fuel production, where hardly any additional land is needed, when more fossil fuel is to be produced. Also, contrary to fossil fuel, biomass production is renewable, is generating low or no net GHG emissions, when no land use change is needed. But low yields per hectare can generally not be multiplied by more than 2 to 4 times. Beyond that increase of land use efficiency, more land, and therefore land use change is necessary. It is for all these reasons that land use issues are so important in food and biomass production.

III/ Increasing land use efficiency to cope with climate variability at the national level.

Increasing land use efficiency is, as shown above, a good option, when compatible with local environmental constraints, not only to increase food production on already cultivated land but also for climate change mitigation. Is it also a good option to better adapt to greater climate variability and ultimately to climate change?

With for instance a possible decrease of 20% of mean average (e.g. five year) cereal crop yields, as shown in fig. 12, it would be still preferable, at national levels, to start by increasing land use efficiency, at least when considering the total national average production. This would allow to sell grain to other regions or countries during years with good crop yields, and to buy grain from other countries when local yields are too low to meet national demand. Part of the exceeding production during good yield years could also be stored in silos and be used later, during national low yield years. But grain storage has also a cost. Each country is therefore to decide what is the best option.

Climate insurance schemes may also, but only to some extent in semi-arid regions, help farmers not to take too high risks when using fertilizer.

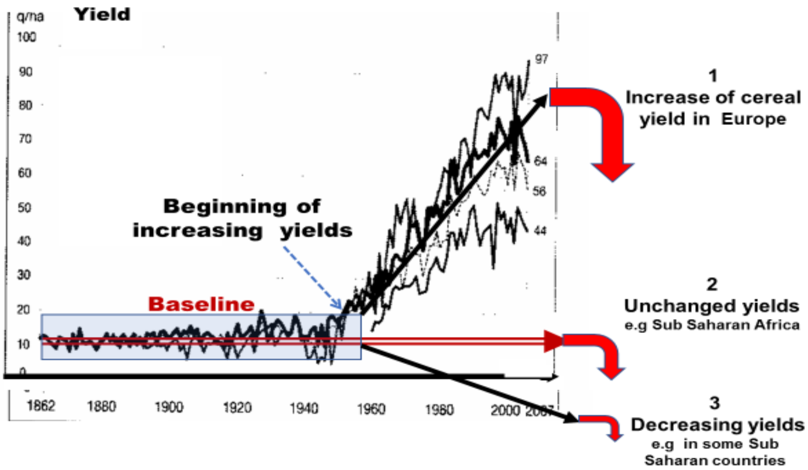

Fig. 12: Schematic evolution of average cereal crop yields since the 1860's, in European countries (1) and in African countries (2) & (3). Until the 1960s, average yields in Europe were low, almost as low as in Africa today. Assuming a 20 % average yield decrease due to climate change, the result is still better, when average yields have first been increased as (1) in Europe, (2) than with previously unimproved yields, and even more (3) when yields per ha have decreased due to insufficient inputs.

Evolution schématique des rendements des céréales depuis les années 1860, en Europe (1) et dans les pays Africains (2) et (3). Jusqu'en 1950 les rendements moyens étaient bas en Europe, presque aussi bas qu'en Afrique. En admettant que le changement climatique se traduise par une diminution des rendements moyens de 20%, le résultat est plus favorable (1) quand les rendements moyens ont au préalable été augmentés comme en Europe, que (2) lorsque les rendements n'ont au préalable pas été augmentés, ou (3) quand ceux-ci ont diminué par suite d'apports insuffisants d'intrants.

V/ Fertilizer and other agricultural subsidies in different countries of the world and sustainable development

Should agricultural subsidies be increased or removed in some countries to achieve sustainable development?

OECD countries. Many OECD countries subsidize directly or indirectly their farmers: subsidies are close to 60% of gross agricultural income in Norway, close to 50% in Switzerland, South Korea, and Japan, and in average about 20% in OECD countries They are however close to zero in New Zealand and Australia. (OECD 2015a), Fig13.

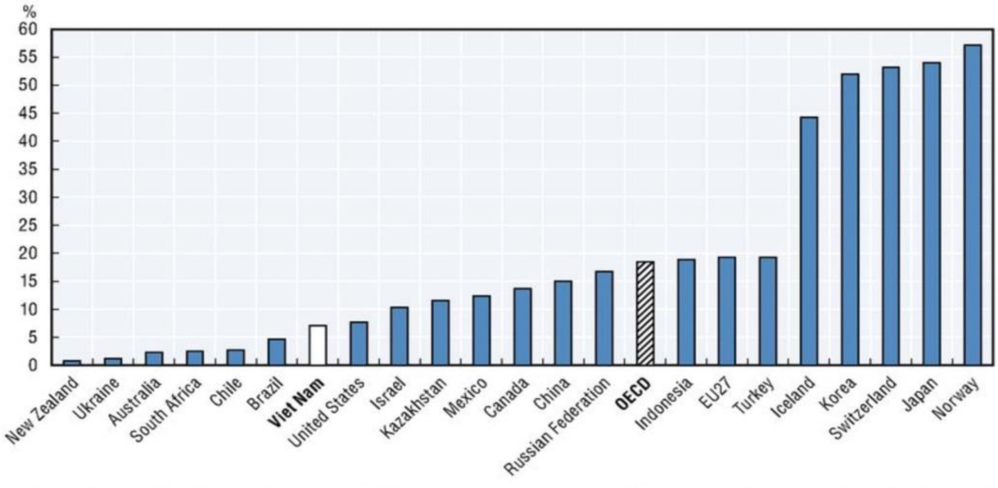

Fig. 13: Farmer support estimates in selected countries (percent of Gross farm receipts (2011-2013 average). Soutiens aux agriculteurs dans quelques pays (pourcentage des recettes des ventes (2011-2013) From OECD (2015), Agricultural policies, Vietnam 2015, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264235151-en

In 2010, the EU average agricultural subsidy per ha was 271 €, but with large variations: 450 € in Belgium and the Netherland, 400 € in Italy, 300 € in Germany and France, and 600 € in Malta and only 60 € in Leetonia. The total budget of the Common Agricultural Policy for 14 million farms reached 58 billion € in 2010 (Bauer 2010).

Level agricultural supports of rich and emerging countries are now converging towards 15% of their production (Fig. 14 below, from Debard & Douillet (2015).

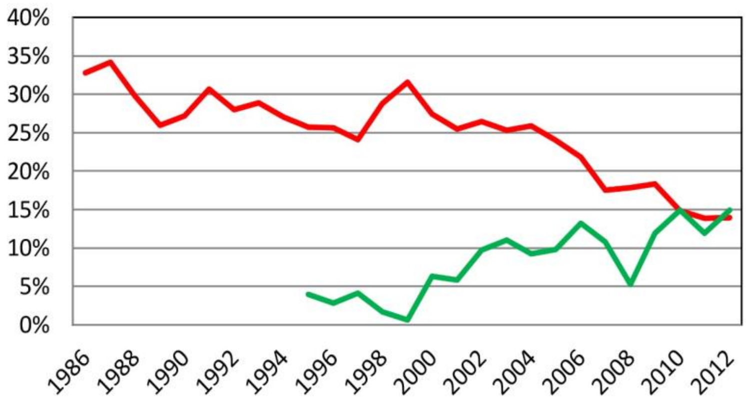

Fig. 14: Evolution of mean percent of agricultural support to producers in rich (above) and emerging countries (below), based on OECD calculations. Respective mean supports are now converging at about 15% .
Évolution des soutiens moyens à la production agricole dans les pays riches (en haut) et dans les pays émergents, (en bas) sur la base de calculs de l'OCDE. Les soutiens entre pays riches et émergents convergent maintenant autour de 15% (Debard & Douillet 2015).

In developing countries subsidies are quite variable: table 1 below indicates subsidies for some developing countries as % of total government expenditures in 2011

In Sub-Saharan Africa (SSA), after a depressed period of more than two decades following the structural adjustment that removed national fertilizer subsidy programs (in many African countries they were close to zero), fertilizer has gained momentum since 2009 albeit from a very low base (IFDC /FAI (2017). They were particularly important for the budget of Malawi and Bangladesh (respectively 17.5% and 11.9% of

the total Government Expenditure). Malawi made a huge effort to end food crisis which regularly occurred in this very poor country before the fertilizer and seed support program introduced by former president Mutharika (Future Agricultures 2008). According to official data, annual maize production reached 3.23 million tons in 2010, about twice as much as during the 1994-2005 period. (Douillet, 2001). As reported in the New York Times, "the famine ended simply by ignoring Free-Market experts" (Dugger 2007).
But average net imports of agricultural products are increasing in Sub-Saharan Africa since 1980 (CFSI 2011). Insufficient efforts are made in most African countries to increase food production at a rate that would be adequate, both to improve food security and to limit GHG emissions. Why is this objective yet far from being, in practice, sufficiently supported by the international community and countries wanting to promote sustainable development, e.g. mitigate sufficiently the climate change and to produce enough food to eradicate hunger by 2030?

Subsidies are important in some Latin America countries: average subsidies, between 1985 and 2001, as part of total rural expenditures, reached 87% in Brazil, 69% in Argentina, 64% in Peru, etc. (FAO 2012 table 1)

Table 1: Comparison of Fertilizer Subsidy Expenditure, 2011 in selected countries - Comparaisons des aides pour l'agriculture et les engrais dans quelques pays en développement (IFDC /FAI 2017).

Country	Total Gov. Exp. (as % of GDP)	Total Gov. Exp. (U.S. $ M)	Fertilizer Subsidy (U.S. $ M)	Subsidy as % of Total Gov. Exp.
Bangladesh	9.80%	12,607	1,498	11.9%
China	22.57%	1,691,042	21,810	1.3%
India	14.30%	262,521	14,610	5.6%
Indonesia	15.00%	133,945	1,520	1.1%
Pakistan	17.60%	37,621	506	1.3%
Nigeria	6.00%	24,705	409	1.7%
Malawi	15.00%	844	148	17.5%
Rwanda	15.00%	961	10	1.0%
Tanzania	16.60%	5,624	64	1.1%
Total	12.59%	2,169,870	40,575	1.87%

Note: Error in totals can occur due to rounding.

In China and India Fertilizer Subsidies were also important, but represented a much lower part of the of the total Government Expenditure, as these countries are already industrialized and have a much higher GDP per capita than African countries. In India, food, fertilizer and petroleum is subsidized, but food and fertilizer subside are much higher than those for petroleum. Fig. 15 shows the evolution of fertilizer subsidies

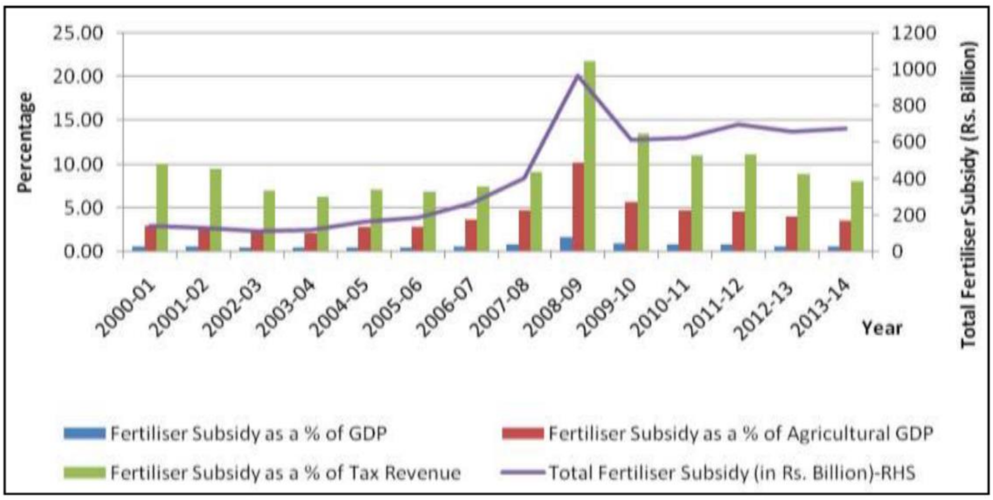

Fig. 15: Total fertilizer subsidy (in Rs. Crore), and as a percentage of different variables, in India.
Subventions totales des engrais (en 10 millions de roupies) et en pourcentage de différents paramètres. (Chart 4 from Gulati and Banerjee, 2015)

It is often claimed that removing fossil fuel subsidies would reduce GHG emissions. This may be helpful in most sectors, but not for crop production, because of the fundamental difference between biomass production (a direct conversion of solar energy needing land) and fossil fuel production as already underlined above. Taxation was recommended as a Policy Instrument in the last 2014 IPCC report of Group III (table 15.2, page 1158,) to reduce GHG emissions in Energy, Transport, Building and Industry Sectors. Before the Kyoto Protocol and even more recently, the efficiency and feasibility of introducing carbon taxes to reduce fossil fuel consumption were widely discussed (Godard 2015). But today they are often much too low, less than $ 15, to induce switching for instance from coal to natural gas, emitting per toe (ton of oil equivalent = 42 GJ) of primary energy only about 2.4 t CO_2, instead more than 4 t of CO_2 for coal. For that change to become economically feasible, carbon taxes should be at least twice as high. And for CCS (Carbon Capture and Storage of CO_2) which is another option to bring sufficiently down CO_2 net emission, they would need be even higher, (between $ 50 and $ 100 per ton of avoided CO_2 emission)! Some recommend also that new investments for further fossil fuel exploration should no longer be supported. Despite signs of decline, overall support of fossil is still high, about USD 160 billion (OECD 2015b).

For all these reasons, although desirable, we think that it is unlikely to be economically, and therefore be politically feasible to reduce sufficiently deeply and rapidly GHG emissions from fossil fuel to meet the objective of the Paris agreement, by tackling fossil emissions only.

To achieve emission reductions, some business NGOs proposed already in 1995- during the approval of the Report of Group 3 of the IPCC Second Assessment Report in Montreal - to remove also agricultural subsidies. But this was not accepted, as for agriculture there did not exist any study to prove the efficiency of such a measure. (IPCC 1995). In the proposal for the 1995 Ipcc summary for policy maker of it was also already suggested to increase yields per hectare in Sub-saharan countries. But due to lack of support of African delegates and to the specific interest of the Swiss delegate in organic farming, the proposal was not included in the final Summary for Policy Maker approved by delegates of UN countries.

But should agricultural inputs (e.g. fertilizer) be taxed? Surprisingly, this is what, some IPCC economists suggested recently in table 15.2. of the last 2014 IPCC report of Group III. They did propose to introduce Fertilizer or Nitrogen taxes to reduce nitrous oxide emissions resulting from nitrogen input in the AFOLU (Agriculture, Forestry, and Land Use) sector. But this is exactly the opposite of what should be recommended where land use efficiencies are still low, as today especially in African and Least Developed countries! Even in Europe more net energy can be produced per ha by using efficiently mineral input: with 170 kg of N on wheat, the net energy gain per hectare is 110.5 GJ, instead of only 63.5 GJ with no mineral nitrogen input (EFMA 2012). To produce the same amount of net energy without nitrogen input, 1,74 ha instead of 1 ha would be necessary: This would require deforestation or grassland conversion of 0.74 ha! Based on indications of fig. 6 of the SPM, average additional GHG emissions that would result from that can be easily calculated. This would exactly end up with the opposite result of what is required to mitigate climate change, to produce more biomass and to preserve environmental services. As shown above, when food production is to be increased, yields should be increased first, before considering expanding the area of cultivated land.

How can then this misleading recommendation for agriculture, of table 15.2 mentioned above, be explained? Most climate economists are familiar with fossil fuel issues, but do not really understand, as too often, the difference between fossil fuel production, and renewable biomass production. They treat therefore the two issues in the same way, ignoring that to produce more food, either land use efficiency is to be increased, or more land is to be converted into cropland! With fossil fuel, as already emphasized, land use is not an issue! In agriculture it is necessary, first to understand properly the issue and to consider changes resulting from land use and land use change in the whole world! Let's hope that this error will be corrected in future IPCC reports.

Official UNFCCC greenhouse gas inventories are not sufficient for decision makers. The latter should base their decision at least on two types of GHG emissions inventories: on their national GHG emissions reports under the requested format for United Nation Climate Convention Office in Bonn, and also on an another inventory to take adequate decisions in agriculture and forestry (Riedacker 2008a). As when dealing with food and biomass production, a little more input can increase gross GHG emission when crop production is not considered, but can reduce net GHG when total crop production is considered (Riedacker 2008a and 2008 b). UN inventories only considers emissions within each country, but neither GHG from international transportation, nor shadow GHG emissions from imported goods. Similarly, emissions generated during production of exported goods are also not deducted from emissions of that exporting country. (In France, UN emissions per capita, reached about 6.7 t of CO2e with the UNFCCC format, but at least 9 t of CO_{2e} when shadow emissions from imported goods were also considered (Commissariat général au développement durable, 2010)!

Under the WTO organization rules, agricultural subsidies are, since 2001, allowed up to 5% of the value of the products in developed countries, up to 10% in developing countries and up to 8.5% in China.
In China and India, respectively 28.8% and 13.5% of the world fertilizer market, fertilizer subsidy support is now an integral component of their Green Revolution. Subsidized fertilizer represents 54% of the world demand. Slightly over 50% of global fertilizer use was for cereal crops. (IFDC /FAI (2017).

According to Washington and the OECD, Chinese agricultural subsidies are too high. They may have reached 23% of the total agricultural products between 2013-2015. In 2015, for wheat, maize and rice alone, it was considered that they were $ 100 billion above the authorized level for these three products. On this basis, the US government filed a complaint against China in September 2016. China on his side claimed that these subsidies are allowed under the WTO and are now a regular international practice (Hiault 2016).
It is easy to imagine how removing all agricultural subsidies would reduce land use efficiencies and end up with more deforestation and large land use change and more GHG emission if the same amount of food was to be produced. With the necessity to increase food production this would even be worse and drastically increase GHG emissions, a trend completely opposite to what countries wanted to achieve by ratifying the Paris Climate Agreement in 2016!

In contrast to that, in most African and Least Developed countries agricultural subsidies are too low. Up to recently African farmers got fertilizer through the National Cotton Companies. And they did use part of the fertilizer for that crop to increase also yields of other crops. But large subsidies of US cotton farmers, and also some mismanagement in some African countries, led recently to the collapse of this system in several countries. And African cotton producer, contrary to Brazilian cotton producer, could get no compensation for that (Nubukpo 2011).

And the FAO, suggested to link financial support to limit climate change with the adoption of smart agricultural practices (FAO 2012). Preliminary calculations showed for instance that in Malawi, a subsidy of only $ 15 per ton of avoided CO_2 emission due to reducing the necessity of land use change, would allow to divide by two the national cost of agricultural subsidies.
Despite of this interest, contrary to developed countries, it is still not widely accepted that African governments should subsidize inputs. Officially governmental agricultural subsidies in Malawi are considered to represent a too high percentage of public expenditures (table 1). But unofficially, some completely liberally minded experts and donors consider that governments should not intervene at all in this business. By recommending that, they however seem to completely ignore the importance of agricultural policies and measure, especially in the U.S, since the 1929 world crisis, in the EU since the 1960's. And more recently in the US (2091) In addition to that, they also seem to be completely ignorant of the new constraints deriving from the ratification of the Paris Climate Agreement in 2006.

As pointed also by Barklund (2003) large income of *"European and American farmers' originate from direct government payment and subsidies. One can, therefore make a case for a proportion of such subsidies directed towards lowering fertilizer prices for the region",* e.g. in East Africa and other countries with presently low land use efficiencies. *"Such support would promote substantial growth in agricultural production and rural income and thus make a direct contribution to poverty reduction for a large portion of the population".* In 2009 rice production has very much increased in Mali – from an average of 1.5 t per ha up to 2.5 t per ha- due to a 50% subsidy per bag of fertilizer (Harel 2009).
Replacing food aid by fertilizer subsidies would be a good idea to prevent human climate catastrophes. How? , is an issue that can be discussed (Minot et Benson 2009). Unfortunately, it seems not yet to be an interesting option for food aid and charity business organizations.

The question of subsidies for fertilizer must be addressed not only for poverty reduction and to meet future food demand due to the expected population growth, especially in Sub-Saharan Africa, but also to minimize land use change and GHG emissions. As looking at forests alone (Karsenty & Pirard 2007) is insufficient to meet the UN objectives.

How much of the funds promised by the developed countries under the Paris Agreement is likely to be transformed into subsidies for agricultural inputs? Presently probably not very much.

- Due to very high inter-annual variations of crop yields, and the request of Monitoring, Reporting and Verifying (MRV) of changes under the Clean Development Mechanism of the Kyoto Protocol, the latter mechanism is inapplicable to raise agricultural production per hectare.
- Can inputs, to increase yields, be funded under the NAMA's (Nationally Appropriate Mitigation Actions)? Probably not. As of August 2016, only 16% of the NAMA's registered were in the AFOLU sector. And FAO supports AFOLU NAMA process only as a learning tool. China has for instance asked for assistance under this mechanism, not to increase yields, but to reduce its very high average nitrogen input, without reducing yields. (see above).

Although not ignoring at all the interest of increasing agricultural inputs in their country, exporting countries of agricultural products are not very eager to help, in the short term, to increase land use efficiencies in other countries. In Paris, for instance, the State Secretary of the US recommended, during a side event at the 2015 UN Climate Conference, that to face the climate change challenge all economic barriers should be removed: this would allow poor people of all countries to buy food at the lowest cost! But in that case, where would this food be produced? And what about the balance of trade of countries which will have to import more food (Gupta (1999)? The General Director of the WTO, without mentioning the specificity of agricultural productions, wrote also just after the Paris Climate Agreement, that Trade can be transformed into a winning card for the climate (Azevedo 2015). Trade can of course help to mitigate irregular rainfall as indicated above. But such exchanges are to take place in regulated markets, and not just by removing all barriers. Some economists recommended also to remove asymmetry of market information to improve the functioning of international markets. But this is very unlikely to happen. Developed countries such as EU, U.S. Japan etc., as well as developing country want to protect their food production and food security. India wanted for instance even to subsidize its grain reserves for food security, which was not allowed in the past under the WTO agreement. The EU introduced the CAP (Common Agricultural Policy) in the 1960's. Without such innovation, EU and U.S. food production could not have been raised up present levels (Boussard 2004).

There are also some historical and ideological reasons for not subsidizing agricultural input. In some discussion reports of the World Bank the necessity of intensifying agriculture in Sub-Saharan countries and increasing chemical and organic inputs was well recognized. But immediately after that, it was also stated that agricultural policies should first be reformed, and that all subsidies for agricultural inputs and food should be removed (Cleaver and Donovan 1995)!
It is still not widely accepted that African governments should subsidize agricultural inputs. Officially governmental agricultural subsidies in Malawi are considered to represent a too high percentage of public expenditures (table 1). But unofficially some completely liberally minded experts and donors consider also that governments should not intervene at all in these activities. By recommending that, they however seem to completely ignore the importance of agricultural policies and measure, especially in the U.S, since the 1929 world crisis, and in the EU, since the 1960's. In addition to that, they also seem to be completely ignorant of the new constraints deriving from the ratification of the Paris Climate Agreement in 2016.
Most developed countries prefer also to sell their products. Some support afforestation of degraded land in their mitigation programs for developing countries. It sounds nicer for their countrymen than to support agricultural inputs. But is it smart and fair?

From a political point of view, for this to change would suppose first that African decision makers are aware that increasing and improving their agricultural inputs (fertilizer, lime, seed, water etc.), as recommended inter alia, by the NEPAD at the 2006 Abuja conference, is a good option *both* to increase food security and for climate change mitigation.
In addition to that they should also want to ask for it, and then dare to put this on the negotiating table! Unfortunately, contrary to other great regions of the world, Sub-Saharan African countries had, up to 2015, no agronomist in their climate negotiation delegations!

Fortunately, at COP 22 conference in Marrakech, in November 2016, in Morocco, the hosting government of the conference promoted the triple A (Adaptation of African Agriculture) initiative: both to improve food security in this continent and to mitigate climate change. Many conferences in side events at the Moroccan Pavilion explained how land use efficiency could be increased, inter alia, with more adequate levels of agricultural inputs and, like in developed countries and many developing countries, by analyzing soils to find out how much mineral input is required.

Here we insisted primarily on increasing mineral and organic inputs. Increasing rain water harvesting in semi-arid regions, water pumping, or improving rural markets and training of farmers are of course also to be supported, if the global community is to meet the 2050 target on climate mitigation and food security, and the 2030 U.N. goals for eradication of hunger. Subsidizing ruminant fodder production in some developing countries, to reduce the amount of methane generated by ruminant per kg of milk or meat, should also be considered. This is however not detailed here due to space limitation.

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