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Quantifying nitrogen losses in oil palm plantations: models and challenges

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Table SM1. Nominal, minimum and maximum values of inputs variables and parameters, used for the Morris' sensitivity analysis. EF: emission factor; C: carbon; N: nitrogen; BNF: biological nitrogen fixation; EFB: empty fruit bunches, i.e. organic fertiliser.

Input variables and parameters	**Nominal (min.-max.)***	**Unit**	**References***
Rainfall	2407 (1500-3000)	mm.yr-1	Ecozones, from FAO (2001)
Mean temperature	28 (20-30)	°C	Ecozones, from FAO (2001)
Soil bulk density	1430 (860-1550)	$kg.m^{-3}$	(Soil taxanomy, from USDA, 1999) (Khasanah et al., 2015)
Soil carbon content	1.68 (0.6-2.38)	%	(Corley and Tinker, 2003, p.84) (Khasanah et al., 2015) (Soil taxanomy, from USDA, 1999)
Soil clay content	31 (1.6-35)	%	(Soil taxonomy, from USDA, 1999)
Soil C/N	11 (10-12)	-	(Nemecek, 2012)
Soil N organic / N total	0.85 (0.68-1)	-	±20% (Nemecek, 2012)
Soil N mineralisation rate	1.6 (1.28-1.92)	%	±20% (Roy, 2005)
Soil N organic	5500 (1700-5700)	$kgN.ha^{-1}$	(Nemecek, 2012) (Soil taxanomy, from USDA, 1999)
Soil pH	4.5 (4-6)	-	(Corley and Tinker, 2003, p.84)
Oil palm rooting depth	1 (0.5-5)	m	(Jourdan and Rey, 1997);(Schroth et al., 2000); (Sommer et al., 2000); (Ng et al., 2003); (Corley and Tinker, 2003); (Nelson et al., 2006); (Lehmann, 2003); (Paramananthan, 2015)
Oil palm N uptake	189 (40-380)	$kgN.ha^{-1}.yr^{-1}$	(Xaviar, 2000);(Goh et al., 2003);(Tan, 1976); (Tan, 1977);(Ng, 1977);(Pushparajah and Chew, 1998); (Henson, 1999); (Ng et al., 1999); (Ng and Thamboo, 1967); (Ng et al., 1968); (Foster and Parabowo, 2003)
N released by felled palms (above- and below-ground)	275 (0-321)	$kgN.ha^{-1}.yr^{-1}$ (N is released in two years)	(Khalid et al., 1999b);(Khalid et al., 1999a); (Redshaw, 2003); (Schmidt, 2007)
N released by palm residues (fronds, roots, etc.)	108 (0-182)	$kgN.ha^{-1}.yr^{-1}$	(Corley and Tinker, 2003); (Redshaw, 2003); (Carcasses, 2004); (Turner and Gillbanks, 2003); (Schmidt, 2007); (Dufrêne, 1989); (Lamade et al., 1996); (Henson and Chai, 1997); (Jourdan et al., 2003)
Mineral fertiliser amount	94 (25-206)	$kgN.ha^{-1}.yr^{-1}$	(Henson, 2004); (Banabas, 2007); (Choo et al., 2011); (Foster, 2003); (FAO, 2004, In Schmidt, 2007); (Carcasses, 2004); (Hansen, 2005); (United Plantations Berhad, 2006); (Wicke et al., 2008)

Urea rate in mineral fertiliser	25 (0-100)	%	(FAO, 2004, In Schmidt, 2007); (Carcasses, 2004)
Organic fertiliser amount (EFB)	184 (0-228)	$kgN.ha^{-1}.yr^{-1}$	(Banabas, 2007); (Redshaw, 2003)
Atmospheric N deposition	18 (8-20)	$kgN.ha^{-1}.yr^{-1}$	(Agamuthu and Broughton, 1985); (Chew et al., 1999); (Trebs et al., 2006)
Biological N fixation	150 (0-190)	$kgN.ha^{-1}.yr^{-1}$	(Giller and Fairhurst, 2003); (Ruiz and López, 2014); (Broughton et al., 1977); (Agamuthu and Broughton, 1985);
Legume N uptake	66 (0-150)	$kgN.ha^{-1}.yr^{-1}$	(Agamuthu and Broughton, 1985)
N released by legume residues	120 (0-190)	$kgN.ha^{-1}.yr^{-1}$	(Agamuthu and Broughton, 1985); (Pushparajah, 1981)
EF (IPCC 2006) Leaching and runoff, from mineral and organic fertilisers and BNF	30 (10-80)	%	(IPCC, 2006)
EF (IPCC 2006) NH_3 from mineral fertiliser	10 (3-30)	%	(IPCC, 2006)
EF (IPCC 2006) NH_3 from organic fertiliser	20 (5-50)	%	(IPCC, 2006)
EF (IPCC 2006) N_2O from mineral and organic fertilisers, BNF and plant residues	1 (0.3-3)	%	(IPCC, 2006)
EF (Mosier 1998) Leaching and runoff from mineral and organic fertilisers	30 (3-57)	%	±90%
EF (Mosier 1998) NH_3 from mineral fertiliser	10 (1-19)	%	±90%
EF (Mosier 1998) NH_3 from organic fertiliser	20 (2-38)	%	±90%
EF (Mosier 1998) N_2O from mineral and organic fertilisers, BNF and plant residues	1.25 (0.125-2.375)	%	±90%
EF (Asman 1992) NH_3 from Ammonium Sulfate	8 (0.8-15.2)	%	±90%
EF (Asman 1992) NH_3 from Urea	15 (1.5-28.5)	%	±90%
EF (Schmidt 2007) NH_3 volatilisation from Ammonium Sulfate	2 (0.2-3.8)	%	±90%
EF (Schmidt 2007) NH_3 volatilisation from Urea	30 (27-48)	%	(Corley and Tinker, 2003, In Schmidt, 2007 p102)
EF (Agrammon 2009) NH_3 from leaves	2 (0.2-3.8)	$kgN.ha^{-1}.yr^{-1}$	±90%
EF (Agrammon 2009) NH_3 from organic fertiliser	35 (30-80)	%	(Agrammon Group, 2009, In (Nemecek et al., 2014)
EF (Nemecek 2007) NO_x emissions from N_2O emissions	21 (2.1-39.9)	%	±90%
EF (Crutzen 2008) N_2O from mineral fertiliser and BNF	4 (3-5)	%	(Crutzen et al., 2008)
EF (EMEP 2013) NO_x from mineral fertiliser	2.6 (0.5-10.4)	%	(Stehfest and Bouwman, 2006, In European Environment Agency, 2013)
EF (EMEP 2013) NH_3 from Ammonium Sulfate, low pH	1.3 (0.13-2.47)	%	±90%
EF (EMEP 2013) NH_3 from Ammonium Sulfate, high pH	27 (2.7-51.3)	%	±90%
EF (EMEP 2013) NH_3 from Urea, low pH	24.3 (2.43-46.17)	%	±90%
EF (EMEP 2013) NH_3 from Urea, high	24.3	%	±90%

pH	(2.43-46.17)		
EF (Vinther and Hansen 2004) N_2O from mineral and organic fertilisers, BNF and plant residues	1 (0.1-1.9)	%	±90%
Parameter (Vinther and Hansen 2004) N_2/N_2O rate	3 (0.3-5.7)	%	±90%
Parameter (Meier 2014) N Use Rate	70 (7-133)	-	±90%
Parameter 1 (Shcherbak et al., 2014)	0.0181 (0.017-0.019)	-	(Shcherbak et al., 2014)
Parameter 2 (Shcherbak et al., 2014)	6.58 (6.45-6.71)	-	(Shcherbak et al., 2014)

*When no references are mentioned, the range was set arbitrary to ±90%, otherwise the range is taken from the references.

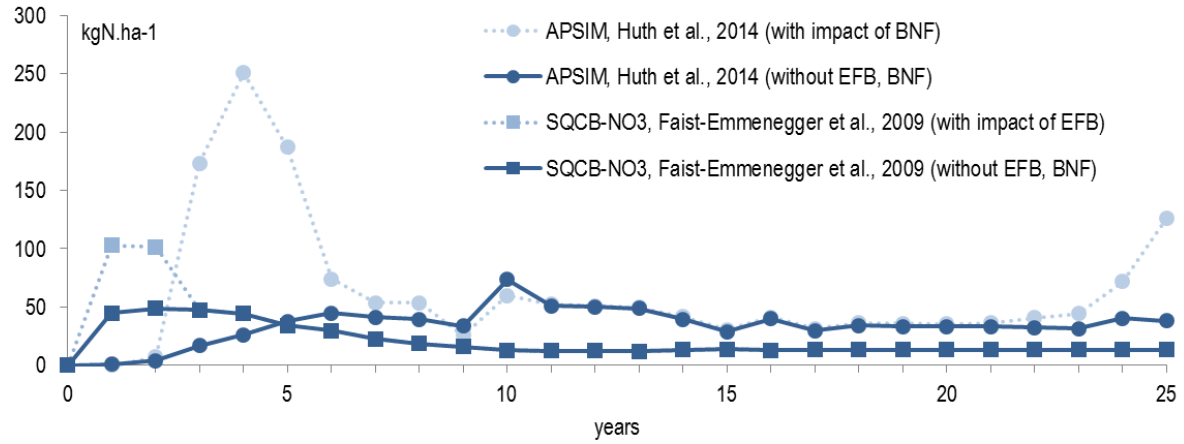

Figure SM1. **Influences of EFB and BNF on the temporal patterns of losses through leaching and runoff**. The timing of the peak of losses depended on models, and its magnitude depended on which N inputs were accounted for. Two examples are represented: the influence of BNF in APSIM, and the influence of EFB in SQCB-NO3. BNF: biological N fixation; EFB: empty fruit bunches, i.e. organic fertiliser.

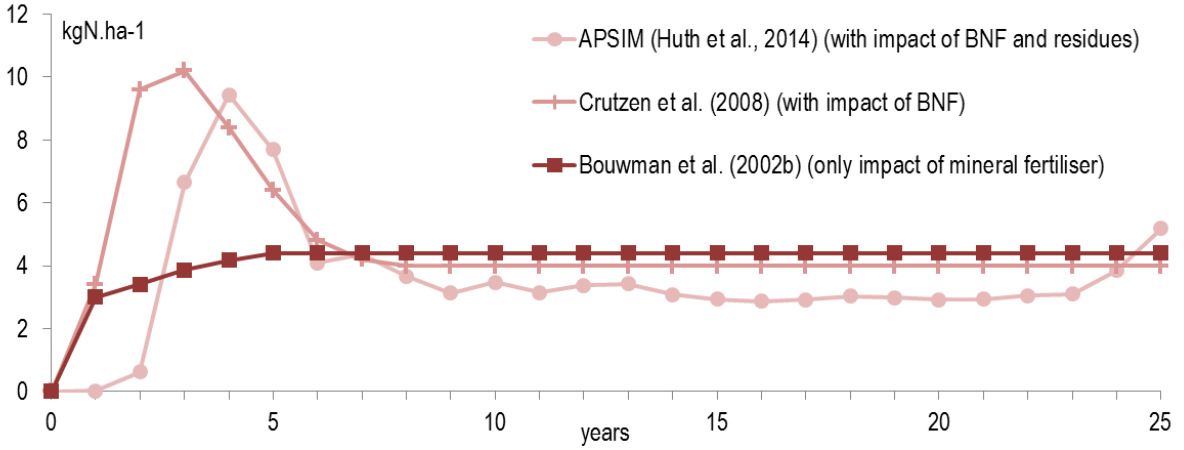

Figure SM2. Influences of previous palm residues, EFB and BNF on the temporal patterns of losses through N_2O emissions. The sub-models that included mineral fertiliser inputs only did not show any peak of emissions over the crop cycle, e.g. in Bouwman 2002b, whereas the ones taking into account at least one other N input, such as palm residues or biological N fixation, showed a peak during the immature period. Three examples are represented: Bouwman 2002b (regression model, influence of mineral fertiliser), Crutzen 2008 (linear regression model, influence of mineral fertiliser and BNF), and APSIM (mechanistic model, with influence of BNF, and previous palm residues). BNF: biological N fixation.

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