Supplementary Material

Yield dynamics of crop rotations respond to farming type and tillage intensity in an organic agricultural long-term experiment over 24 years

Wiebke Niether[a*], Janna Macholdt[b], Franz Schulz[a], Andreas Gattinger[a]

[a]Department of Agronomy and Plant Breeding II, Organic Farming with focus on Sustainable Soil Use, Justus-Liebig University Giessen, 35394 Giessen, Germany

[b]Department of Agronomy and Organic Farming, Martin-Luther-University Halle-Wittenberg, 06120 Halle (Saale), Germany

*corresponding author: wiebke.niether@agrar.uni-giessen.de (W. Niether)

Materials and Methods A.1 Adaptations in the crop rotations

In the course of a long-term trial, adaptation of the field management is done according to agronomic practices. This includes also the adaptation of new and modern varieties. In 1997, winter wheat was sown in all plots to establish the trial. In SFL and SFC it remained as the first crop, while it was replaced by alfalfa grass-clover mix in MF in early 1998. In the following crop rotations, oat was cropped at the first position in SFL and SFC. In MF, an oat-pea-clover mix was at the fifth position of the first crop rotation that was later on replaced by a second winter wheat crop. In SFL and SFC, the fifth position of the crop rotation was pea for three crop rotations, then replaced by soy, when variety test trials confirmed good soy production under the conditions as Gladbacherhof with a higher protein yield per hectare than pea. In the cropping year 2015 to 2016 that marked the beginning of the fourth rotation, the treatment combinations MFxTLP30/15 and SFCxTLP30/15 were reversed on the field; the yield data from these plots in 2016 were removed from the data set. In respect to a potential legacy effect, we recalculated the whole dataset removing the data from the entire fourth crop rotation for the farming and tillage combinations MFxTLP30/15 and SFCxTLP30/15; the temporal yield level and yield stability changed slightly but the main effects of farming type and tillage and the combination remained as before. To maintain a higher number of data in the set we kept the dataset at it was.

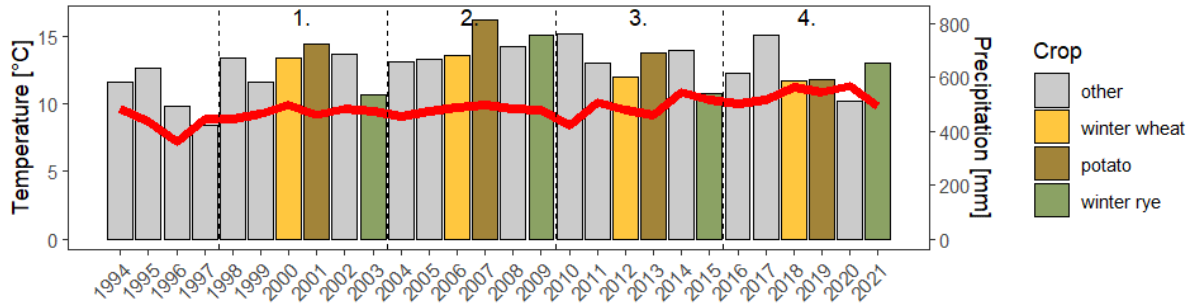

Fig. A.1 Mean annual temperature (line) and annual precipitation (bars) at the weather station Gladbacherhof (1994-2021). The segments indicate the four crop rotations. The weather records started prior to the beginning of the trial in 1994 since some weather parameters can also influence the years after e.g., annual precipitation sum can affect the groundwater recharge.

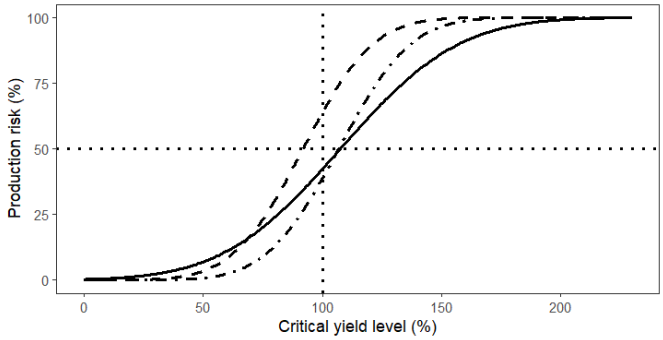

Fig. A.2 Yield risk of target crops wheat (dashed line), potato (solid line) and rye (dot-dashed line) to fall below a range of critical yield levels (yield range from 0 to 200% of average yield at the experimental farm) across farming system and tillage intensity. Dotted lines indicate a critical yield of 100% and a production risk of 50%, respectively.

Table A.1 a) Crop and varieties used in the OAFEG; b) reference crops and average yield at Gladbacherhof from 1994 to 2020 (GH 100%). Soy was produced within the *Official Variety Trials* by the German Federal Plant Variety Office 2018 to 2020 (LLH, 2022).

a)

Crop	Varieties	Production year
Alfalfa grass clover mix	Verko, Europe, Kerem, Lipperry, Lirocco, Belimo, Lifelix, Milka	1998
Winter wheat	Thasos	1998
Alfalfa grass clover mix	Verko, Europe, Kerem, Lipperry, Lirocco, Belimo, Lifelix, Milka	1999
Faba bean	Scirocco	1999
Winter wheat	Renan	2000
Potato	Exempla	2001
Oat pea clover mix	Flipper, Classic	2002
Pea	Classic	2002
Winter rye	Amilo	2003
Alfalfa grass clover mix	Planet, Maro, Lifara, Lirocco, Sponsor	2004
Oat	Flämingsprofi	2004
Alfalfa grass clover mix	Planet, Maro, Lifara, Lirocco, Sponsor	2005
Faba bean	Divine	2005
Winter wheat	Achat	2006
Potato	Princess	2007
Winter wheat	Akratos	2008
Pea	Respect	2008
Winter rye	Amilo	2009
Alfalfa grass clover mix	Plato, Leia, Lischka, Cosmolit	2010
Oat	Flämingsprofi	2010
Alfalfa grass clover mix	Plato, Leia, Lischka, Cosmolit	2011
Faba bean	Fuego	2011
Winter wheat	Akratos	2012
Potato	Granola	2013
Winter wheat	Capo	2014
Pea	Respect	2014
Winter rye	Recrut	2015
Alfalfa grass clover mix	Plato, Twymax, Lischka, Cosmolit	2016
Oat	Max	2016
Alfalfa grass clover mix	Plato, Twymax, Lischka, Cosmolit	2017
Faba bean	Bilbo	2017
Winter wheat	Elixer	2018
Potato	Soraya	2019
Winter wheat	Capo	2020
Soy	Sphinxa	2020
Winter rye	Inspector	2021

b)

Reference crop (Gladbacherhof)	Varieties	Production years	Total area (ha)	Average yield (Mg ha^{-1})	Crop in long-term experiment
Faba bean	Alfred; Hedin; Scirocco; Condor; Gloria; Music; Divine; Espresso; Fuego; Bilbo; Julia	1994-1998; 2001-2018	187.1	3.18	Faba bean
Pea	Baronesse; Duell; Swing; Classic; Pinocchio; Classic; Phönix; Harnas	1995; 1998-2005	43.8	2.42	Pea
Silage crops (summer wheat-pea mix)	NA	1998	2.3	12.96	Oat-pea-clover mix
Oat	Alfred; Flipper; Flämingsprofi; Max; Bison	1994-1996; 2001-2012; 2014-2018; 2020	87.4	3.85	Oat
Potato	Linda; Granola; Agria; Simone; Exempla; Cilena: Princess; Charlotte	1994-2018	92.7	24.91	Potato
Alfalfa grass	Europe/Schöll; NA	1995-1998; 2012-2015; 2017-2019	308.0	14.80	Alfalfa grass clover mix
Winter rye	Camilo; Danko; Conduct; Carotop; Dukato; Recrut	1994-2020	224.2	3.90	Winter rye
Winter wheat	Bussard A9; Fregatt; Sperber A7; Astron A6; Alidos; Batis; Renan; Ludwig; Aristos; Achat; Capo; Akratos; Türkis; Philipp; Aszita; Philaro; Elixir; Butaro; Aristaro	1994-2020	279.1	4.02	Winter wheat
Soy (Official Variety Trial by LLH)	Merlin; Amarok; Coraline; ES Comandor; GL Melanie; Taifun 8; Tofina; Viola; Acardia; ES Favor; Marquise; RGT Sphinxa; Abelina; Aurelina; Nessie PZO; Simoncine; Alicia	2018-2020	NA	3.72	Soy

Table A.2 Linear mixed-effect models (in R syntax) used for analysis of the relative yield (mean) and the yield stability (adjusted coefficient of variance: aCV) over time of the whole crop rotation and single target crops for fixed factors tillage intensity and farming type and random factors block and position in crop rotation.

Data	Model
Crop rotation	mean~tillage_intensity*farm_type + (1|block)+(1|position), data
	(aCV)^0.5~tillage_intensity*farm_type + (1|block)+(1|position), data
Winter wheat	log(mean)~tillage_intensity*farm_type + (1|block), data
	log(aCV) ~tillage_intensity*farm_type + (1|block), data
Potato	mean~tillage_intensity*farm_type + (1|block), data
	(aCV)^0.25 ~tillage_intensity*farm_type + (1|block), data
Winter rye	mean~tillage_intensity*farm_type + (1|block), data
	(aCV)^1.5 ~tillage_intensity*farm_type + (1|block), data

Table A.3 Production risk of the crop rotation and the target crops to fall below the critical yield value of 100% GH for farming type (MF: mixed farming; SFL: stockless farming with ley; SFC: stockless farming with cash crops) and tillage intensity (P30: deep inversion; TLP30/15: two-layer inversion; P15: shallow inversion; CR30/15: non-inversion).

	Crop rotation (%)	Winter wheat (%)	Potato (%)	Winter rye (%)
Farming type				
MF	46.1	72.0	30.6	42.9
SFL	42.9	38.7	46.3	32.1
SFC	49.5	93.5	52.1	42.3
Tillage intensity				
P30	41.6	53.2	43.4	21.3
TLP30/15	45.1	57.3	41.5	42.9
P15	43.2	57.1	42.3	35.7
CR30/15	54.7	82.2	41.6	56.2