Sustainability of agricultural practices in Germany: a literature review along multiple environmental domains

Marieke Cornelia Baaken[1,2]

[1]Helmholtz Centre for Environmental Research GmbH, Department of Environmental Politics, Leipzig, Germany
[2]Philipps-University Marburg, Department of Economics, Research Group Sustainable Use of Natural Resources, Marburg, Germany

*** Correspondence:**
Email: marieke.baaken@ufz.de

Supplementary Material 5: Practices and their impact on environmental and economic domains

Table 2. Effects of fertilizer practices on the environment

PRACTICES „FERTILIZER STRATEGIES"	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
Acidification	P (1)	N/A	N/A	N/A	N/A
Adjust N fertilization to crops needs	CP (2)	P (1)	P (1)	N/A	N/A
Ammonium bicarbonate	N (1)	N (1)	N (1)	N (1)	N/A
Anaerobic digestate of manure	P (1)	P (1)	P (1)	P (1)	N/A
Band spreading	P (1)	P (1)	P (1)	P (1)	N/A
Bedding systems	P (1)	N/A	N/A	N/A	N/A
Change of fertilizer rate	P (4)	U (2)	P (3)	N (1)	N/A
Controlled release fertilizer	CP (2)	CP (2)	CP (3)	CP (2)	N/A
Covers for manure storage	P (1)	N/A	N/A	N/A	N/A
Crop residue retention	U (4)	P (5)	N (3)	CN (2)	N/A
Deep placement of fertilizer	P (3)	CP (2)	CP (2)	CP (2)	N/A
Deep-pit systems	N (1)	N/A	N/A	N/A	N/A
Delay of fertilizer application	N (1)	N/A	N/A	N/A	N/A
Fall vs. spring fertilizer application	NN (1)	N/A	N/A	N/A	N/A
Farmyard manure application	N/A	P (2)	N/A	N/A	N/A
Fertilize using macerate from herbs or plants for spraying	N/A	N/A	P (1)	N/A	N/A
Fertilizer mixed with amendments (pyrise, zeolite & organic acids)	P (1)	P (1)	P (1)	P (1)	N/A
Fertilizer with nitrification inhibitors	U (4)	N (3)	U (4)	CN (2)	P (1)
Fertilizer with urease & nitrification inhibitors	P (1)	N/A	N/A	N/A	N/A

Fertilizer with urease inhibitors	CP (3)	CP (2)	CP (2)	CP (2)	N/A
Incorporation	P (1)	P (1)	P (1)	P (1)	N/A
Injection	P (1)	P (1)	P (1)	P (1)	N/A
Manure and mineral fertilizer	N/A	P (1)	N/A	N/A	N/A
Manure storage covers for slurry manure	P (2)	N/A	N/A	N/A	N/A
Mineral fertilizer	N/A	P (2)	N/A	N/A	N/A
Non-urea based fertilizer	P (1)	P (1)	P (1)	P (1)	N/A
Organic fertilizer/no fertilizer	NN (2)	P (5)	P (1)	CP (2)	U (3)
Organic soil amendments application	P (2)	P (4)	N/A	N/A	NN (1)
Organic soil amendments application; biochars	CP (3)	P (3)	CP (2)	N/A	N/A
Organic soil amendments application; raw manure	P (3)	N/A	N/A	N/A	P (1)
Polymer-coated urea	NN (2)	N/A	N/A	N/A	N/A
Pull-plug systems	N (1)	N/A	N/A	N/A	N/A
Reduce protein content	P (1)	P (1)	P (1)	P (1)	N/A
Separation of solid and liquid manure	P (1)	P (1)	P (1)	P (1)	N/A
Separation systems	P (1)	N/A	N/A	N/A	N/A
Shallow injection of manure	U (1)	N/A	N/A	N/A	N/A
Slurry fertilizer (manure in liquid form)	N/A	NN (2)	N/A	N/A	N/A
Specific fertilizer sources	P (1)	P (1)	P (1)	P (1)	N/A
Split application	NN (2)	NN (2)	NN (2)	NN (2)	N/A
Store manure in field heaps	N/A	N/A	P (1)	N/A	N/A
Treat manure; use anaerobic digesters	P (1)	N/A	N/A	N/A	N/A
Urea ammonium nitrate	NN (2)	NN (1)	NN (1)	NN (1)	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 3. Effects of cultivation practices on the environment

PRACTICES „CULTIVATION"	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
Abandonment of formerly plowed fields	N/A	P (1)	N/A	N/A	N/A
Antitranspirants in drought management of arable crops	N/A	N/A	P (1)	P (1)	P (1)
Cereals	U (2)	N/A	N/A	N/A	CN (2)
Controlled traffic farming	P (1)	P (1)	P (1)	N/A	P (1)
Cover crops	U (9)	P (15)	P (11)	CP (3)	P (4)
Crop diversification	CP (2)	P (1)	N/A	CP (2)	CP (3)
Crop establishment	N/A	P (1)	N/A	N/A	N/A
Crop rotation	N (2)	U (8)	U (2)	CP (3)	CP (3)

Cropped plant-weed competition by manipulating cropped cover	N/A	P (1)	N/A	N/A	N/A
Effluent application on pastoral soils	P (1)	N/A	N/A	N/A	N/A
Fallow improvement	P (1)	P (1)	N/A	N/A	N/A
Field selection	N/A	P (1)	N/A	N/A	N/A
Grain legumes as pre-crop	N/A	N/A	P (1)	N/A	N/A
In-field plants	N/A	N/A	N/A	P (1)	N/A
Intercropping	P (1)	U (8)	P (4)	CP (2)	P (4)
Intercropping with undersown cover	N/A	N (1)	N/A	P (1)	N/A
Irrigation	CP (3)	CP (3)	CP (3)	CP (2)	N/A
Low density non irrigated vineyards	N/A	N/A	P (1)	N/A	U (1)
Mechanical weed control tools	N/A	P (1)	N/A	N/A	N/A
Micro irrigation systems	N/A	N/A	P (1)	N/A	N (1)
No or natural herbicides	P (1)	P (1)	P (1)	P (1)	P (1)
No or natural pesticides	P (1)	P (1)	P (1)	P (1)	P (1)
No-tillage	P (1)	U (10)	U (3)	P (3)	U (2)
Organic matter addition	N/A	P (1)	N/A	P (1)	P (1)
Precision agriculture	N/A	NN (1)	NN (1)	N/A	N/A
Reduced tillage/conservation tillage/less intensive tillage practices	U (5)	P (14)	CP (2)	CP (3)	P (5)
Sida hermaphrodita and silphium perfoliatum as energy crops	P (1)	P (1)	N/A	P (1)	N/A
Weed pathogenic fungi	N/A	P (1)	N/A	N/A	N/A
Weedy fallow	N/A	N/A	P (1)	N/A	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 4. Effects of vegetation practices on the environment

PRACTICES „PLANTING: VEGETATION, LANDSCAPE ELEMENTS & OTHER“	CLIMATE	SOIL	WATER	BIODIV.	ECONOMIC DIMENSION
Agrisilvicultural systems	NN (2)	CP (5)	CP (3)	P (4)	P (4)
Beetle banks	N/A	P (1)	N/A	P (1)	N/A
Boundary planting	P (1)	NN (1)	N/A	N/A	N/A
Enrichment planting	P (1)	P (1)	N/A	N/A	N/A
Field margin plants (several plants & nectar & flowering plants)	CP (1)	P (1)	N/A	CP (2)	N/A
Field margin plants (trees & shrubs)	NN (1)	P (1)	N/A	P (1)	N/A
Flower type (nectar, quality, timing & quantity)	N/A	N/A	N/A	P (1)	N/A
Grassed waterways, terraces, contour farming, filter strips and/or riparian buffers	P (2)	P (2)	CP (5)	P (2)	NN (3)

Habitats for beneficial insects (growing cultivars)	N/A	N/A	P (1)	P (1)	N/A
Hedgerows and/or woody plantings	CP (1)	N/A	P (1)	CP (2)	NN (1)
Homegardens	NN (1)	P (1)	N/A	N/A	N/A
Introduce field margins, field edges and paths, headlands, fence-lines, rights of way, and nearby uncultivated patches of land, maintenance, and restoration of hedgerows and other vegetation features at field boarders	N/A	CP (2)	P (1)	CP (4)	P (1)
Other plantings (e.g. wide-spaced belts or blocks on hillslopes and gully wall plantings)	CP (2)	CP (2)	CP (2)	P (1)	N/A
Passive and active restoration of agroecosystems (land sharing and land sparing)	N/A	N/A	N/A	P (1)	N/A
Perennials	CP (2)	CP (2)	P (1)	N/A	P (1)
Remnant	N/A	P (1)	N/A	P (1)	N/A
Revegetation	N/A	P (1)	N/A	NN (1)	N/A
Riparian vegetation	N/A	CP (1)	P (1)	P (1)	N/A
Short-rotation woody cropping in silvicultural systems	N/A	N/A	N/A	N (1)	N/A
Silvopasture	NN (1)	P (2)	N/A	CP (1)	N/A
Skylark plots	N (1)	N/A	N/A	N/A	N/A
Strips and borders of non-crop vegetation around agricultural lands	CP (1)	P (2)	P (1)	CP (3)	NN (1)
Trees on farmland	N/A	P (1)	P (1)	CP (4)	U (1)
Wildflower strips	N/A	P (1)	N/A	P (1)	N/A
Windbreaks/shelterbelts	N/A	P (1)	P (1)	CP (2)	N/A
Woodlots	P (1)	NN (1)	N/A	N/A	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 5. Effects of grazing practices on the environment

PRACTICES „GRAZING STRATEGIES“	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
Complex grazing patterns	N/A	P (1)	N/A	N/A	N/A
Continuous moderate grazing	N/A	P (1)	P (1)	P (1)	N/A
Livestock grazing	N/A	N (2)	N (1)	NN (4)	N/A
Livestock guardian animals	N/A	N/A	N/A	P (1)	P (1)
Rotational/deferred-rotational grazing with low or moderate stocking rates	N/A	NN (3)	NN (2)	P (1)	N/A
Strategic rest grazing	N/A	CP (2)	N/A	NN (1)	NN (1)
Targeted livestock grazing	N/A	N/A	N/A	P (1)	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 6. Effects of feeding practices on the environment

PRACTICES „FEEDING STRATEGIES“	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
Crude protein content reduction	P (3)	P (1)	CP (2)	P (1)	N/A
Cultivation of more nutritious forage plants	P (1)	N/A	N/A	N/A	N/A
Dietary acidifier	P (1)	P (1)	P (1)	P (1)	N/A
Dietary additives (cinnamon extracts, Ferix-3, Al+Clear, zeolite, etc.)	U (3)	P (1)	P (1)	P (1)	N/A
Dietary bacteria	P (1)	P (1)	P (1)	P (1)	N/A
Yucca extract	P (1)	P (1)	P (1)	P (1)	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 7. Effects of stable management practices on the environment

PRACTICES „STABLE MANAGEMENT“	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
Additive usage	NN (1)	NN (1)	NN (1)	NN (1)	N/A
Adsorbent usage	P (1)	P (1)	P (1)	P (1)	N/A
Air scrubbers	P (1)	N/A	N/A	N/A	N/A
Change of relative humidity inside barn	NN (1)	N/A	N/A	N/A	N/A
Change of wind speed inside barn	NN (1)	N/A	N/A	N/A	N/A
Floor management	P (1)	P (1)	P (1)	P (1)	N/A
Frequent manure removal	P (1)	N/A	N/A	N/A	N/A
Lower air temperature inside barn	P (1)	N/A	N/A	N/A	N/A
Lower ventilation rates	P (1)	N/A	N/A	N/A	N/A
Mechanical management (air and manure cleaning systems)	P (1)	P (1)	P (1)	P (1)	N/A
Urease inhibitors	P (1)	P (1)	P (1)	P (1)	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 8. Effects of other practices on the environment

PRACTICES „OTHER“	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
(woodchip) Bioreactors	N/A	N/A	P (1)	N/A	N/A
Composting & vermicomposting	NN (1)	P (1)	P (1)	N/A	N/A
Controlled drainage	N/A	N/A	P (1)	N/A	N/A
Crop livestock integration	P (1)	P (2)	CP (2)	P (1)	CP (2)
Denitrification barriers such as walls, layers & beds	P (1)	P (1)	P (1)	P (1)	N/A
Establishment and maintenance of wetlands	N/A	N/A	P (1)	P (1)	N/A
Precision livestock farming	P (1)	N/A	N/A	N/A	P (1)
Promote livestock (beef)	N (1)	N (1)	N (1)	NN (1)	N (1)
Seedbed preparation or transplant	N/A	P (1)	N/A	N/A	N/A
Streambank fencing	N/A	N/A	CP (2)	N/A	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).

Table 9. Effects of combined practices on the environment

PRACTICES „COMBINED PRACTICES & BUNDLES“	CLIMATE	SOIL	WATER	BIODIV	ECONOMIC DIMENSION
Conservation agriculture	N/A	P (1)	P (1)	P (1)	NN (1)
Conservation plans	N/A	N/A	P (1)	N/A	N/A
Cover crops & no-tillage	N/A	P (3)	P (1)	CP (2)	N/A
Cropland best management practices (i.e. cover crops, nutrient management plans, buffers, conservation tillage)	N/A	N/A	P (1)	N/A	N/A
External organic amendments & cover crops	N/A	P (1)	N/A	N/A	N/A
External organic amendments & no-tillage	N/A	P (1)	N/A	N/A	N/A
Fallow with no-tillage & dead mulches	N/A	N/A	N/A	NN (1)	N/A
Livestock best management practices (i.e. exclusion, buffers, pasture management)	N/A	N/A	P (1)	N/A	N/A
No-tillage & crop rotation/perennial crop & reduced N rate	P (1)	P (1)	N/A	N/A	N/A
Organic agriculture	N/A	P (1)	P (1)	P (1)	NN (1)
Residue retention & no-tillage	N/A	CP (2)	N/A	N/A	N/A
Whole farm best management practices (i.e. combined livestock and cropland best management practices)	N/A	N/A	P (1)	N/A	N/A

Notes: = Consistently negative impact (CN); = Negative impact (N); = Neutral or no significant impact (NN); = Impact unclear (U); = Positive impact (P); = Consistently positive impact (CP); = No data available (N/A).