Supplementary Material to: An open global reference dataset for natural and improved grasslands and its application for validation and area estimation

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The Supplementary Material consists of visual examples of the grassland classes in the global reference dataset and Tables S1 to S5.

Visual Examples of Grassland Classes in the Global Reference Dataset

Below are visual examples of each of the grassland classes in the global reference dataset, including the location, the country, the biome and an explanation of the visual interpretation of the classes.

Natural/semi-natural permanent grasslands with no visible signs of livestock

Latitude, Longitude	14.15020418, 16.7517459
Location	Chad
Biome	Tropical and subtropical grasslands, savannas and shrublands
Classification explanation	This is predominantly a dry area, where the NDVI time series shows value >0.15, which is the threshold used for bare land / grassland. All sub-pixels are considered grassland in this example.

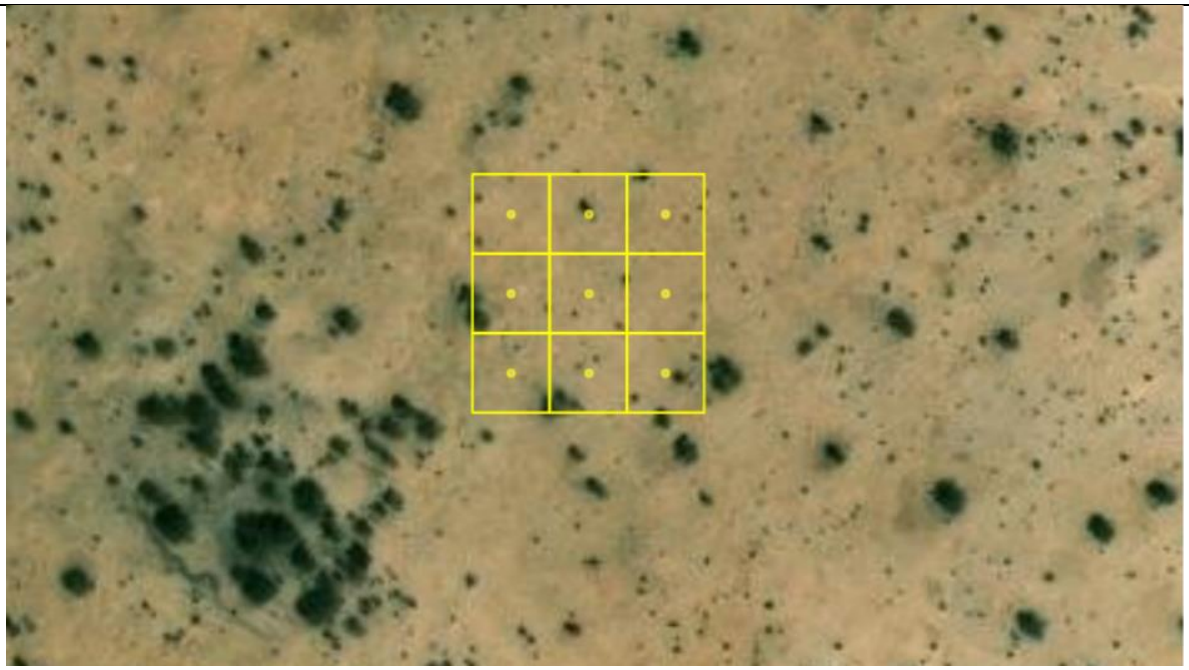


Fig. S1: Natural/semi-natural permanent grasslands with no visible signs of livestock. Image ©2025 Vantor (WV03)

Natural permanent woody vegetation as part of open woodlands with no visible signs of livestock

Latitude, Longitude	11.3047901323, 30.9118670492
Location	Sudan
Biome	Tropical and subtropical grasslands, savannas and shrublands
Classification explanation	All sub-pixels are considered as open woodland



Fig. S2: Natural permanent woody vegetation as part of open woodlands with no visible signs of livestock. Image ©2026 Maxar Technologies

Semi-natural permanent grasslands with visible livestock presence

Latitude, Longitude	5.6205832696, -71.3692680714
Location	Colombia
Biome	Tropical and subtropical grasslands, savannas and shrublands
Classification explanation	The vegetation consists mainly of natural grasses and shrubs, with no planted pastures or evidence of mowing or ploughing in the Sentinel time series. Despite signs of livestock use and related infrastructure, the land cover remains largely untransformed.



Fig. S3: Semi-natural permanent grasslands with visible livestock presence. Image ©2026 Airbus

Temporary grasslands associated with other land use

Latitude, Longitude	23.0367813788, 103.332143439
Location	China
Biome	Tropical and subtropical moist broadleaf forests
Classification explanation	Historical imagery shows dynamic shifts between grassland and cropland. Google Earth imagery indicates pasture in 2018 and cropland in 2019. The location is considered grassland in an intermediate land-use phase (≤4 years), with change.



Fig. S4: Temporary grasslands associated with other land use. Image © 2024 Vantor (WV02)

Improved permanent grasslands associated with livestock

Latitude, Longitude	52.0502461624, 78.00704763
Location	Kazakhstan
Biome	Temperate grasslands, savannas and shrublands
Classification explanation	Regularly managed grasslands with intense mowing visible on Google Earth and in the Sentinel time series. Trails and water ponds are visible.

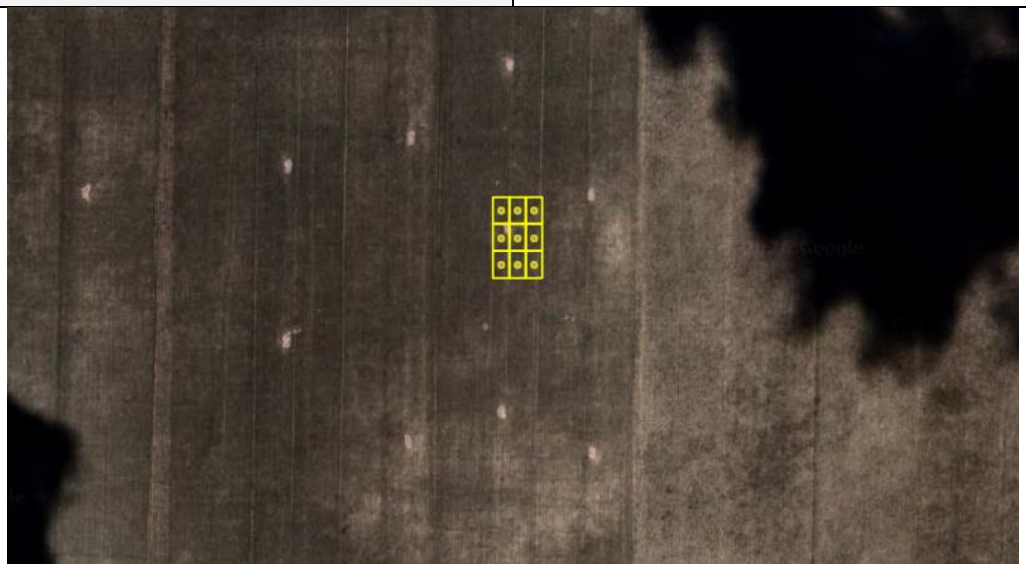


Fig. S5: Improved permanent grasslands associated with livestock. Image ©2026 Airbus

Improved permanent grasslands associated with other land use

Latitude, Longitude	35.4788282082, -97.2424797893
Location	United States
Biome	Temperate grasslands, savannas and shrublands
Classification explanation	Residential/recreational area with regularly managed grasslands used for recreation



Fig. S6: Improved permanent grasslands associated with other land use. Image ©2026 Airbus

Natural permanent open woodlands with visible livestock presence

Latitude, Longitude	-39.6338982678, -64.8584390666
Location	Argentina
Biome	Temperate grasslands, savannas and shrublands
Classification explanation	Shrubland with grazing infrastructure, including watering points, visible in the surrounding area. Horses are also present.



Fig. S7: Natural permanent open woodlands with visible livestock presence. Image ©2023 Vantor(WV03)

Other land cover

Latitude, Longitude	-4.4192915719, 16.2722679175
Location	Congo DRC
Biome	Tropical and subtropical grasslands, savannas and shrublands
Classification explanation	Time-series analysis indicates a mixed cropland/pasture system, with short-term shifts in land cover from grasslands to cultivated cropland.



Fig. S8: Other land. Image ©2019 Vantor (WV02)

Table S1: Inter-annotator agreement across all locations (50045, including sites annotated by one expert but in agreement with the non-grassland strata). The overall agreement is 81.0%. Agreement is in bold along the diagonal of the matrix, grey shaded cells show disagreement greater than 1%.

Classes		Annotator 2								
		Improved permanent grasslands associated with livestock	Improved permanent grasslands associated with other land use	Natural permanent open woodlands with visible livestock presence	Natural permanent woody vegetation as part of open woodlands	Natural/semi-natural permanent grasslands with no visible signs of livestock	Not sure	Other land cover	Semi-natural permanent grasslands with visible livestock presence	Temporary grasslands associated with other land use
Annotator 1	Improved permanent grasslands associated with livestock	**2.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Improved permanent grasslands associated with other land use	0.0%	**0.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Natural permanent open woodlands with visible livestock presence	0.0%	0.0%	**0.2%**	0.2%	0.2%	0.0%	0.4%	0.3%	0.0%
	Natural permanent woody vegetation as part of open woodlands	0.0%	0.0%	0.2%	**0.7%**	0.7%	0.0%	1.2%	0.3%	0.0%
	Natural/semi-natural perm. grasslands with no visible signs of livestock	0.0%	0.0%	0.2%	0.5%	**7.5%**	0.4%	3.6%	2.2%	0.0%
	Not sure	0.0%	0.0%	0.0%	0.0%	0.2%	**0.4%**	0.6%	0.0%	0.0%
	Other land cover	0.0%	0.0%	0.4%	0.8%	1.8%	0.4%	**65.9%**	1.2%	0.2%
	Semi-natural permanent grasslands with visible livestock presence	0.0%	0.0%	0.1%	0.2%	1.0%	0.1%	1.0%	**3.6%**	0.0%
	Temporary grasslands associated with other land use	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	**0.2%**

Table S2: Inter-annotator agreement for a subset of locations where two annotations by two different experts were provided. The overall agreement is 70.7%. Agreement is in bold along the diagonal of the matrix, grey shaded cells show disagreement greater than 1%.

Classes		Annotator 2								
		Improved permanent grasslands associated with livestock	Improved permanent grasslands associated with other land use	Natural permanent open woodlands with visible livestock presence	Natural permanent woody vegetation as part of open woodlands	Natural/semi-natural permanent grasslands with no visible signs of livestock	Not sure	Other land cover	Semi-natural permanent grasslands with visible livestock presence	Temporary grasslands associated with other land use
Annotator 1	Improved permanent grasslands associated with livestock	**3.4%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Improved permanent grasslands associated with other land use	0.0%	**0.2%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Natural permanent open woodlands with visible livestock presence	0.0%	0.0%	**0.3%**	0.3%	0.4%	0.0%	0.7%	0.4%	0.0%
	Natural permanent woody vegetation as part of open woodlands	0.0%	0.0%	0.3%	**1.0%**	1.1%	0.0%	1.8%	0.5%	0.0%
	Natural/semi-natural perm. grasslands with no visible signs of livestock	0.0%	0.0%	0.3%	0.8%	**11.0%**	0.6%	5.5%	3.4%	0.0%
	Not sure	0.0%	0.0%	0.0%	0.0%	0.3%	**0.2%**	0.9%	0.1%	0.0%
	Other land cover	0.0%	0.0%	0.7%	1.3%	2.7%	0.6%	**49.0%**	1.9%	0.3%
	Semi-natural permanent grasslands with visible livestock presence	0.1%	0.0%	0.2%	0.3%	1.5%	0.1%	1.6%	**5.4%**	0.0%
	Temporary grasslands associated with other land use	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	**0.2%**

Table S3: Validation of the Global Pasture Watch Version 1.0 annual layer for 2020 by continent, based on the 'Narrow definition of Cultivated grasslands' harmonization scenario (Table 3). All values are in percentage. Standard errors accompany all accuracy metrics, indicated by a ± percentage.

Continent	Overall accuracy	User's accuracy			Producer's accuracy		
		Natural/semi-natural grasslands	Cultivated grasslands	UA Other land	Natural/semi-natural grasslands	Cultivated grasslands	Other land
Africa	64.5 ±0.4	58.0 ±0.6	2.6 ±0.5	82.2 ±0.5	74.4 ±0.5	22.5 ±4.1	58.8 ±0.4
Asia	78.5 ±0.3	74.1 ±0.5	3.9 ±0.9	85.2 ±0.4	74.7 ±0.4	25.3 ±4.8	81.3 ±0.3
Australia	72.3 ±0.6	75.0 ±0.7	62.1 ±3.0	66.3 ±1.4	88.0 ±0.5	58.2 ±2.5	46.6 ±0.9
Oceania	78.0 ±3.0	67.4 ±7.2	74.2 ±5.6	87.0 ±3.9	78.4 ±6.1	85.2 ±4.4	73.6 ±3.6
Europe	76.9 ±0.6	74.2 ±1.6	26.9 ±2.0	84.7 ±0.6	44.8 ±1.0	47.4 ±2.7	91.0 ±0.4
North America	75.7 ±0.7	72.6 ±0.7	39.8 ±1.8	81.8 ±0.5	72.7 ±0.5	51.8 ±1.9	79.7 ±0.4
South America	70.3 ±1.2	58.2 ±1.2	44.2 ±1.1	85.5 ±0.5	53.1 ±0.9	76.6 ±1.2	75.4 ±0.4

Table S4: Validation of the Global Pasture Watch Version 1.0 annual layer for 2020 by continent, based on the 'Broad definition of Cultivated grasslands' harmonization scenario (Table 3). All values are in percentage. Standard errors accompany all accuracy metrics, indicated by a ± percentage.

Continent	Overall accuracy	User's accuracy			Producer's accuracy		
		Natural/semi-natural grasslands	Cultivated grasslands	UA Other land	Natural/semi-natural grasslands	Cultivated grasslands	Other land
Africa	53.9 ±0.4	33.1 ±0.6	26.2 ±1.5	82.2 ±0.5	77.6 ±0.8	10.4 ±0.6	58.8 ±0.4
Asia	71.4 ±0.3	53.0 ±0.6	39.2 ±2.2	85.2 ±0.4	76.7 ±0.6	9.4 ±0.5	81.3 ±0.3
Australia	62.0 ±0.7	59.1 ±0.8	82.6 ±2.3	66.3 ±1.4	92.6 ±0.5	20.7 ±0.7	46.6 ±0.9
Oceania	75.8 ±3.0	51.2 ±7.7	79.0 ±5.2	87.0 ±3.9	84.6 ±6.7	75.4 ±4.5	73.6 ±3.6
Europe	77.8 ±0.6	53.8 ±1.9	63.6 ±2.1	84.7 ±0.6	63.5 ±1.7	37.4 ±1.2	91.0 ±0.4
North America	69.5 ±0.4	51.5 ±0.8	68.6 ±1.8	81.8 ±0.5	76.4 ±0.7	24.4 ±0.6	79.7 ±0.4
South America	69.5 ±0.5	36.0 ±1.1	62.1 ±1.1	85.5 ±0.5	70.2 ±1.4	54.8 ±0.9	75.4 ±0.4

Table S5: Continental area estimates (in million ha) from GPW v1 for 2020 using the global reference dataset and for the two harmonization scenarios: S1: Narrow definition of the 'Cultivated grasslands' class and S2: Broad definition of the 'Cultivated grasslands' class. Standard errors are in million ha.

Continent	**Natural / semi-natural grasslands area estimate**		**Cultivated grasslands area estimate**		**Natural / semi-natural grasslands standard error**		**Cultivated grasslands standard error**	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Africa	633.76	346.30	13.55	301.01	6.58	5.77	1.33	5.58
Asia	1022.67	712.17	12.07	322.56	7.89	7.87	1.35	6.31
Australia	422.14	315.53	38.99	145.60	4.25	4.40	1.81	3.73
Oceania	4.53	3.18	6.61	7.96	0.51	0.47	0.54	0.60
Europe	102.17	52.22	25.11	75.05	2.17	1.70	1.37	2.10
North America	565.43	381.77	69.15	252.81	5.52	5.34	2.63	4.77
South America	259.12	120.96	144.03	282.19	4.61	3.44	3.54	4.66