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Effects of early season drought on carbon footprint of milk in northern latitudes

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Introduction

Dairy sector contributes significantly to global greenhouse gas emissions. Meanwhile, climate change exposes challenges to dairy production, and is expected to influence the environmental impacts of the dairy products. For instance, Europe experienced severe drought in the spring and summer of 2022, resulting in substantial agricultural losses. In spring, northern Europe will more often have lower soil moisture levels compared to past averages. (Ruosteenoja et al., 2019).

Early summer droughts cause yield losses of forage crops that cannot be compensated for later in the growing season (Peltonen-Sainio et al., 2021). The lower yield of forage crops may lead to extra off-farm feed inputs and alternative feed composition in the dairy system. However, the resources invested to the cultivation system, such as nitrogen fertilizers, seeds and pesticides are not decreased accordingly. Those may affect the carbon footprint of milk life cycle via on-farm cropping, resources input and the feed uptake by dairy cows. Therefore, this study aims to explore the hypothesis that early season drought conditions may elevate the carbon footprint of milk production.

Methods and Materials

Data were primary collected from the **Viikki Research Farm at the University of Helsinki** in Finland. The farm has a research dairy barn with 61 dairy cows, whose average milk production is 10 000 kg per year. The barn is equipped with GreenFeed system for real time methane emission measurements. Feed is mainly produced on the farm, and it consists of grass silage, feed grain and protein crops (rape and fava bean).

Various **carbon footprint calculators** have been developed for assessing the carbon footprint of milk production following technical specifications on LCA. However, only three carbon calculators out of 64 tested were suitable for farm level carbon audits, as they are scientifically robust, comprehensive and practical (Leinonen et al. 2019). The carbon footprint of milk was analyzed using the Solagro carbon footprint calculator developed by the European Commission (https://solagro.com/works-and-products/outils/carbon-calculator). The weather data were obtained from the Finnish Meteorological Institute. In simulated drought scenario, the yield of grass, barley and oat was projected to reduce by 15%, respectively (Hahn et al., 2021; Peltonen-Sainio et al., 2021).

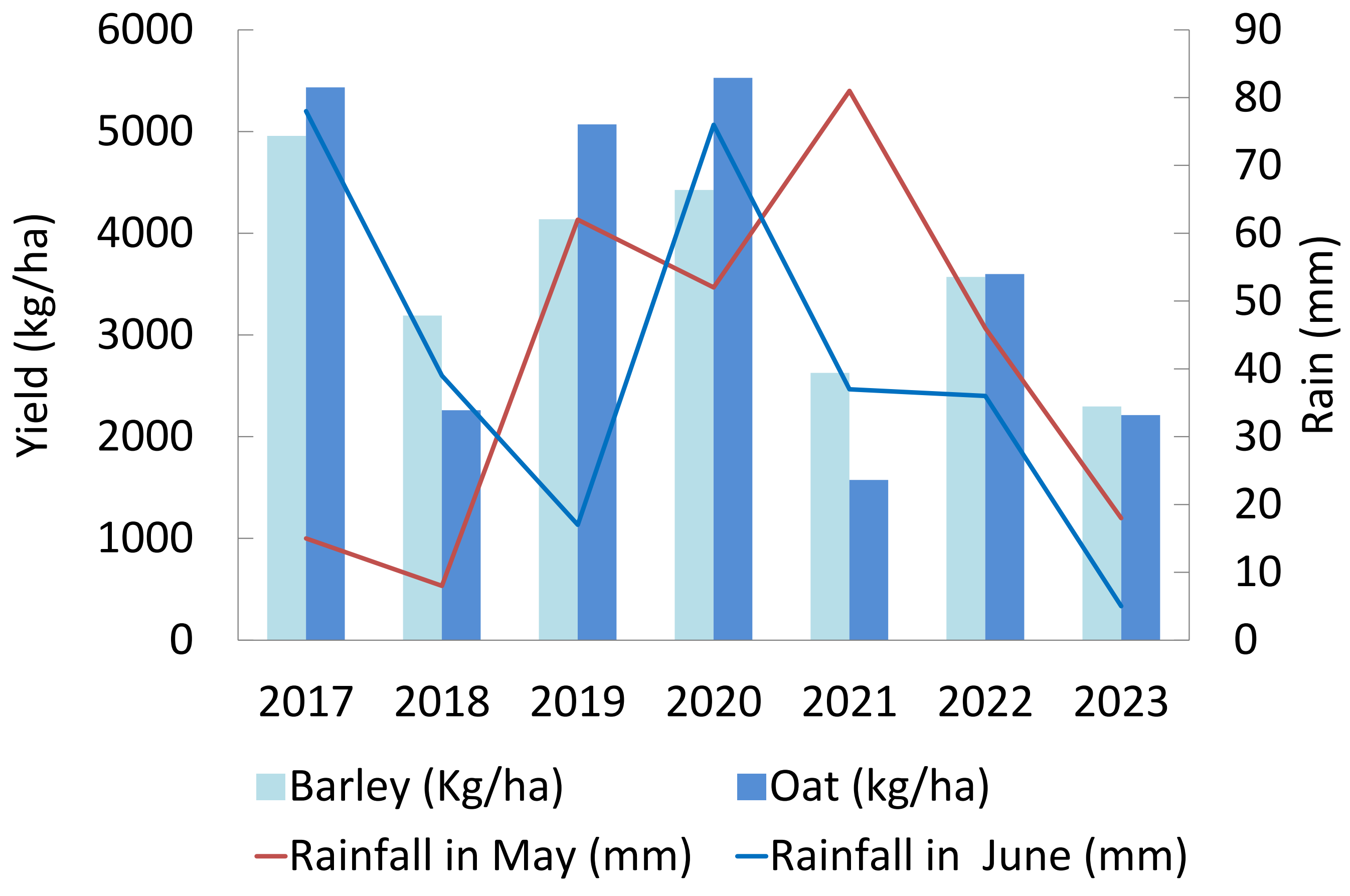

Figure 1. Oat and barley yield levels in 2017-2023 at the Viikki research farm. The red line shows the precipitation in May and the blue line shows the corresponding amount in June.

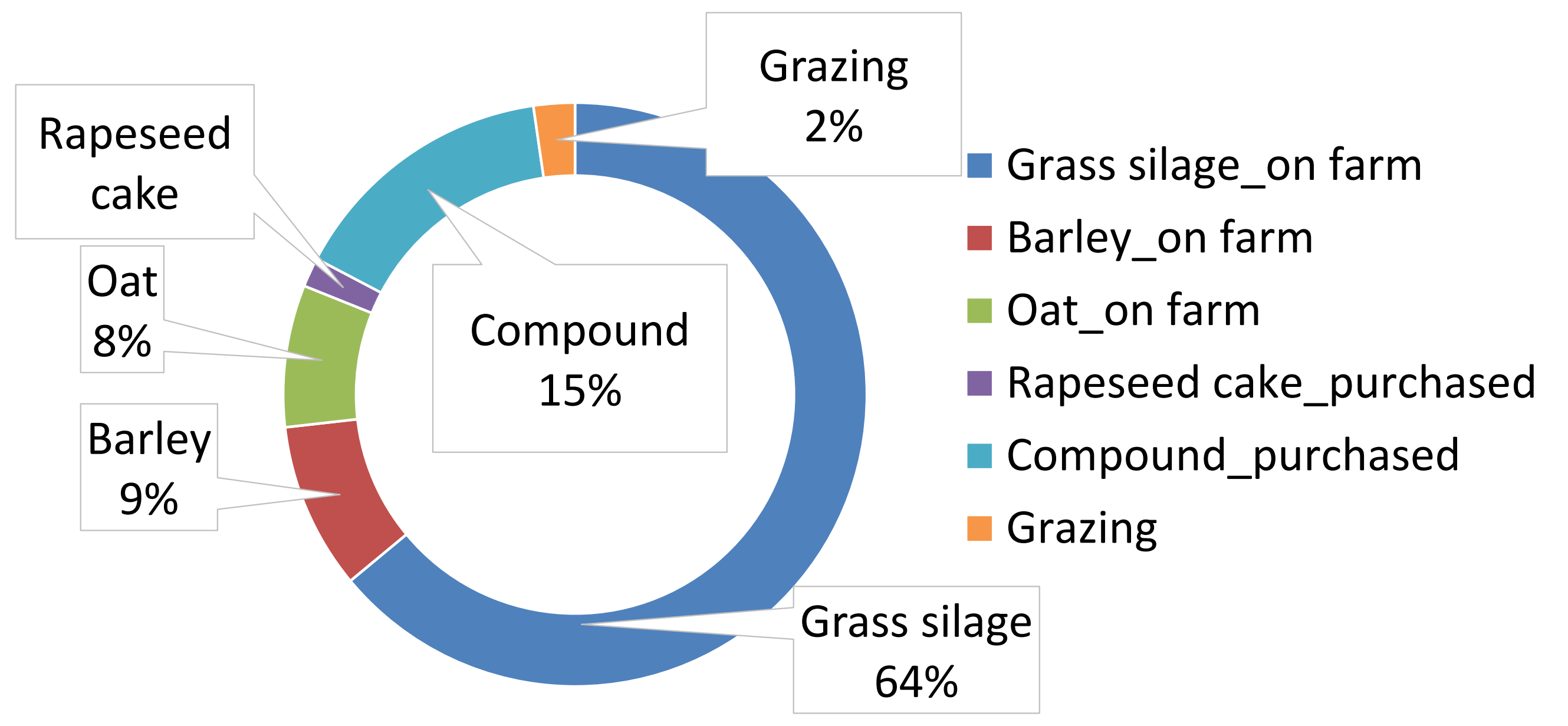

Figure 3. Feed component produced and consumed on the farm

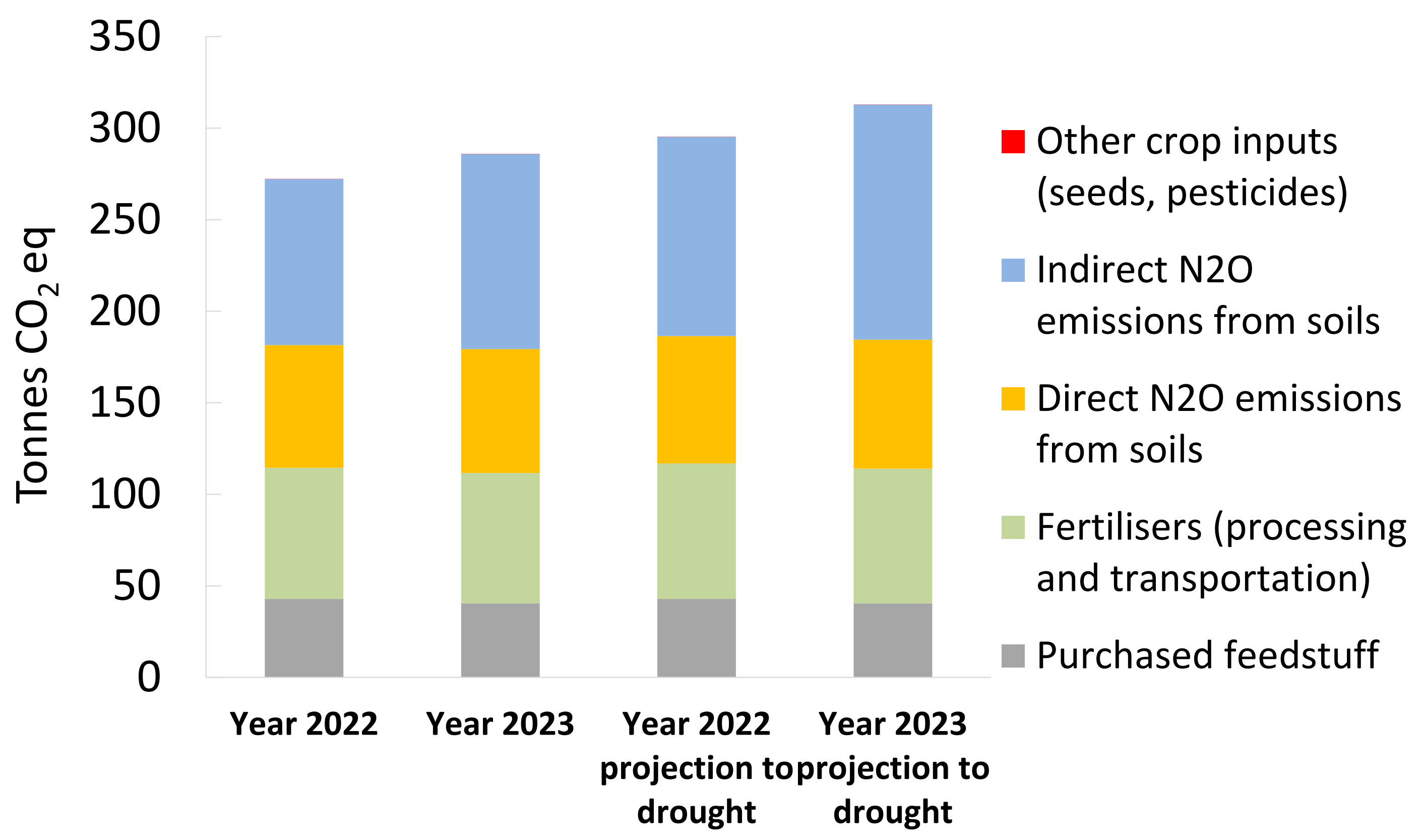

Figure 5. GHG emissions from **feed production** in 2022 and 2023, and projection to early summer drought simulated based on data in 2022 and 2023 at the Viikki research farm.

Figure 2.1. Location of the research farm.

Figure 2.2. Viikki research farmland.

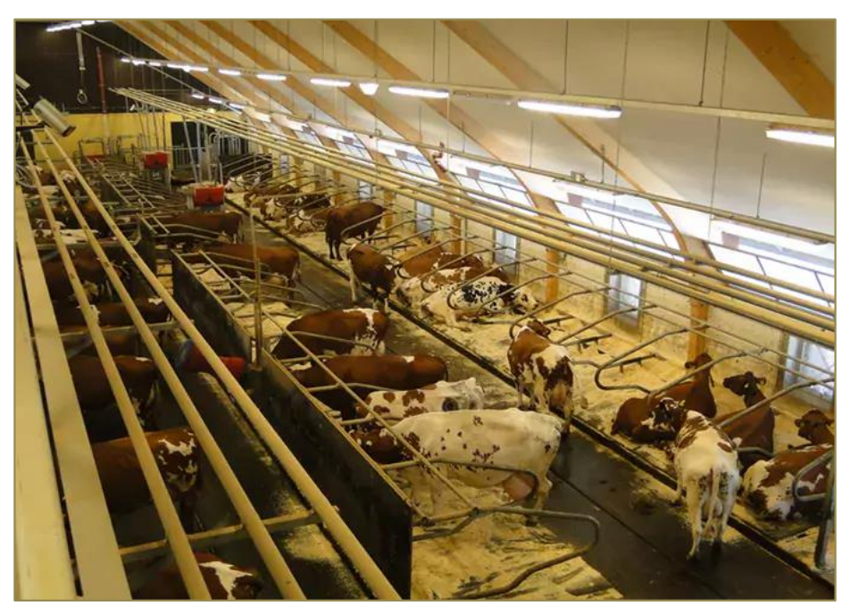

Figure 2.3. Viikki research dairy barn.

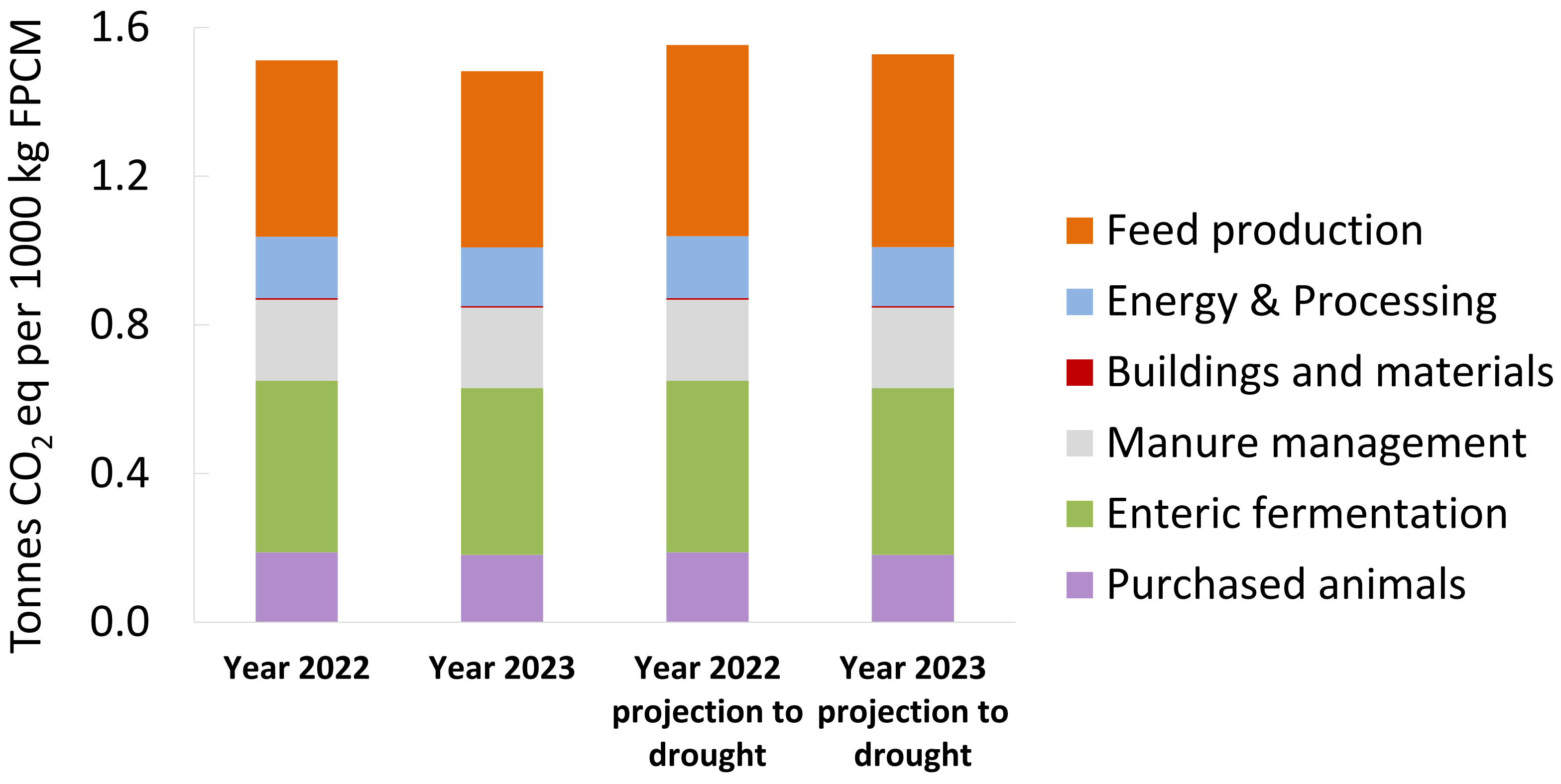

Figure 4. GHG emissions per 1000 kg FPCM from **all sources** in 2022 and 2023, and projection to early summer drought simulated based on data in 2022 and 2023 at the Viikki research farm.

Table 1. Total GHG emissions in 2022 and 2023, and emissions projection to early summer drought simulated based on data in 2022 and 2023 at the Viikki research farm.

GHG emissions ($t\ CO_2$ eq)	Year 2022	Year 2023	Year 2022 projection to drought	Year 2023 projection to drought
Total emissions	867.2	893.8	890.9	921.4
Per 1000 kg FPCM	1.51	1.48	1.55	1.53
Per hectare	10.58	12.04	10.87	12.41

Results and Discussion

Drought conditions in the beginning of the growing season have reduced oat and barley yields on several occasions (Figure 1). However, for grass silage production, later rains in the growing season could mitigate the impact on yields. For instance, grass yield increased from 5808 kg/ha in 2022 to 7784 kg/ha in 2023 due to increased later rains in the growing season in 2023 relative to 2022. In contrast, in year 2018 with drought under the whole growing season, the grass yield remained low as 5500 kg/ha.

Feed produced on farm included grass silage, barley and oat (Figure 3). GHG emissions per hectare increased in 2023 compared with in 2022 primarily due to the loss of crop yield (Table 1). However, results were also affected by the different nitrogen fertilization rate and dry matter intake between the two years. In simulated drought scenario, the yield loss of grass, barley and oat resulted in increased emissions relative to the base year (Table 1). Among all sources of emissions, GHG emissions from feed production were mostly increased (Figure 4), where N_2O emissions from managed soils were main contributors to the increase in GHG emissions from feed production (Figure 5).

In contrast to crops, the loss of grass yield caused by early summer drought can be compensated by the later rains in the growing season. Increasing the proportion of grass-based feed is beneficial to improve resilience to early season drought. Other possible ways could include soil moisture retaining farming techniques and irrigation, which has been identified as a potentially economically viable option for future feed production in Finland (Peltonen-Sainio et al. 2021).

Acknowledgements

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