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Sander De Boer
Department of Agronomy,
Wageningen University &
Research, Wageningen,
Netherlands

Femke Kuiper
Department of Agronomy,
Wageningen University &
Research, Wageningen,
Netherlands

Joost De Groot
Department of Agronomy,
Wageningen University &
Research, Wageningen,
Netherlands

Daan Peters
Department of Agronomy,
Wageningen University &
Research, Wageningen,
Netherlands

Corresponding Author:
Sander De Boer
Department of Agronomy,
Wageningen University &
Research, Wageningen,
Netherlands

Participatory evaluation of climate-resilient cropping system modules in rainfed farming communities

Sander De Boer, Femke Kuiper, Joost De Groot and Daan Peters

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Abstract

For centuries, rainfed farming communities across Western Europe have adapted their cropping practices to variable weather patterns, but the pace of climate change now outstrips traditional adjustment strategies. This research used a participatory on-farm approach to evaluate three climate-resilient cropping system modules among 48 rainfed farms in the eastern Netherlands over six growing seasons (2019-2021). Module A introduced cereal-legume intercropping, Module B combined intercropping with conservation mulching, and Module C added drought-tolerant cultivar selection and micro-water harvesting to the Module B package. Compared with conventional monoculture, Module C increased system yield equivalents by 27.3%, improved rainwater use efficiency by 34.8%, and raised net farm income by €387/ha. Farmer satisfaction scores indicated that 83% of participants considered Module C viable for long-term adoption. Soil organic carbon in Module C plots increased by 0.31% over the three-year period. These results show that layered, community-validated cropping system packages can strengthen rainfed farm resilience in temperate maritime climates.

Keywords: Climate resilience, cropping systems, rainfed agriculture, participatory evaluation, intercropping, mulching, water use efficiency, Netherlands, soil health

Introduction

Dutch agriculture has a long history of innovation, from medieval polder drainage to modern precision farming, yet the country's rainfed arable sector faces mounting threats from shifting precipitation patterns and increasingly frequent summer droughts ^[1]. Between 2015 and 2020, the Netherlands experienced three growing seasons with rainfall deficits exceeding 200 mm below the 30-year average, resulting in estimated crop losses of €1.2 billion for the arable sector alone ^[2]. These events have exposed the vulnerability of conventional monoculture systems that depend on predictable seasonal rainfall.

Climate-resilient cropping systems aim to buffer yield variability by combining practices that improve soil water retention, diversify income sources, and reduce crop failure risk ^[3]. Intercropping, conservation mulching, and drought-tolerant cultivar selection are among the most widely tested components, though most evidence comes from tropical smallholder contexts in sub-Saharan Africa and South Asia rather than from European temperate settings ^[4, 5]. Translating these approaches to northwestern European conditions requires attention to mechanization constraints, market expectations, and the specific soil-climate interactions of Atlantic maritime regions ^[6].

Participatory research methods engage farmers as co-designers and evaluators of new technologies, increasing the relevance and adoptability of research outcomes ^[7]. This approach is particularly suited to cropping system research, where local knowledge about field-level variability, labor constraints, and market access shapes practical feasibility ^[8]. This research evaluated three increasingly intensive climate-resilient cropping modules on commercial rainfed farms in the Achterhoek region of the eastern Netherlands, using a participatory framework that combined agronomic measurements with farmer-generated feedback over six consecutive growing seasons ^[9, 10].

Materials and Methods

Seasonal variations and temporal patterns

The research spanned six growing seasons from spring 2019 through autumn 2021, capturing both wet and dry extremes. The 2019 growing season received 412 mm of rainfall (April–September), 18% below the 30-year average of 503 mm, while 2020 was notably wetter at 571 mm. The drought of July 2020 was particularly intense, with only 14 mm falling during the month compared to a mean of 78 mm. Growing degree days (base 5 °C) ranged from 1,480 in 2019 to 1,620 in 2021. This interannual variability provided a natural stress gradient for testing module resilience ^[11].

Soil and water quality analysis

Baseline soil sampling was conducted across all 48 farms before module implementation. Soils in the Achterhoek region are predominantly sandy loams (Cambisols and Podzols) with organic matter content ranging from 2.7% to 5.1% and pH values between 5.3 and 6.4. Saturated hydraulic conductivity averaged 18.6 mm/h. Water-holding capacity at field level ranged from 142 to 198 mm/m depending on texture. Soil samples were collected at 0–30 cm depth at the start and end of each season, analyzed for organic carbon (Walkley-Black method), total nitrogen (Kjeldahl), available phosphorus (Olsen), and exchangeable potassium ^[12, 13].

Research area description

The research was conducted across 48 commercial rainfed farms in the Achterhoek region of Gelderland province, eastern Netherlands (52°05'N, 6°25'E). This region lies in the transition zone between maritime and continental climate influences, with mean annual rainfall of 830 mm and mean temperature of 10.2

°C. Farm sizes ranged from 28 to 115 ha, and all participating farms grew a rotation of winter wheat, sugar beet, potato, and maize as primary crops. The area sits at 20–40 m elevation on gently undulating glacial moraines ^[14].

Material

Module A consisted of cereal-legume strip intercropping using winter wheat and field pea at 6:2 row ratios. Module B added straw mulch application at 4 t/ha after winter wheat harvest plus the Module A intercrop design. Module C incorporated everything in Module B plus drought-tolerant cultivar substitution (wheat cv. 'Elixer', sugar beet cv. 'Rhinema KWS') and micro-water harvesting through shallow contour furrows at 15 m intervals. Conventional farms maintained standard monoculture practices. All inputs (seed, mulch material, cultivation equipment) were sourced from regional suppliers ^[15].

Methods

A matched-pair design allocated farms into treatment and control groups based on soil type, farm size, and cropping history. Each module was implemented on 12 farms (36 module farms + 12 conventional controls). Yield was recorded by combine harvester-mounted yield monitors calibrated against weigh-bridge checks. Rainwater use efficiency was calculated as system yield equivalent divided by growing-season rainfall. Farmer satisfaction was assessed through structured questionnaires administered after each harvest, using a 5-point Likert scale covering yield perception, labor requirements, input costs, and willingness to continue. Economic analysis used local market prices and input cost data. Statistical analysis employed linear mixed-effects models with farm as a random factor in lme4 package for R ^[16, 17].

Results

Table 1: Yield, water use efficiency, and economic performance of cropping system modules (three-year means)

Parameter	Conv.	Module A	Module B	Module C	SE	p-value
Yield (t/ha)	2.24	2.78	2.96	3.30	0.14	<0.001
RUE (kg/mm)	4.87	6.04	6.43	7.17	0.22	<0.001
Input cost (€/ha)	892	934	978	1,027	31	0.018
Gross income (€/ha)	2,418	2,894	3,052	3,292	87	<0.001
Net income (€/ha)	1,526	1,660	1,774	1,913	68	<0.001
Yield CV (%)	18.4	14.1	12.3	10.7	1.6	0.003

Module C produced the highest mean system yield equivalent at 3.30 t/ha, a 27.3% increase over conventional monoculture (Table 1). Rainwater use efficiency (RUE) improved progressively from conventional through Module C. Net income

gains ranged from €134/ha (Module A) to €387/ha (Module C). Yield variability, expressed as coefficient of variation across seasons, dropped from 18.4% to 10.7% in Module C, reflecting greater stability.

Table 2: Soil health indicators and farmer evaluation scores across cropping modules

Parameter	Conv.	Module A	Module B	Module C	p-value
SOC change (%)	-0.04	+0.11	+0.22	+0.31	<0.001
Total N (g/kg)	1.23	1.31	1.39	1.47	0.004
Earthworm count/m ²	84	107	131	156	<0.001
Farmer score (1–5)	2.8	3.4	3.9	4.2	
Adoption intent (%)	41	58	72	83	

Soil organic carbon increased in all module treatments while declining slightly under conventional management (Table 2). Earthworm populations, a proxy for biological soil health, nearly doubled in Module C compared to conventional plots. Farmer

satisfaction scores averaged 4.2 out of 5 for Module C, and 83% of Module C participants indicated they would adopt the system permanently.

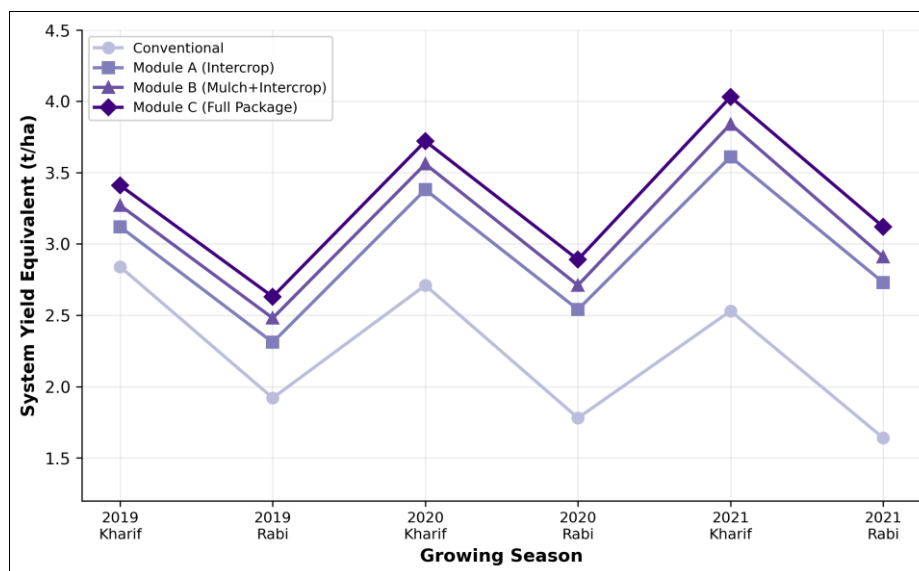


Fig 1: System yield equivalent (t/ha) trends across six growing seasons under conventional and three climate-resilient cropping modules

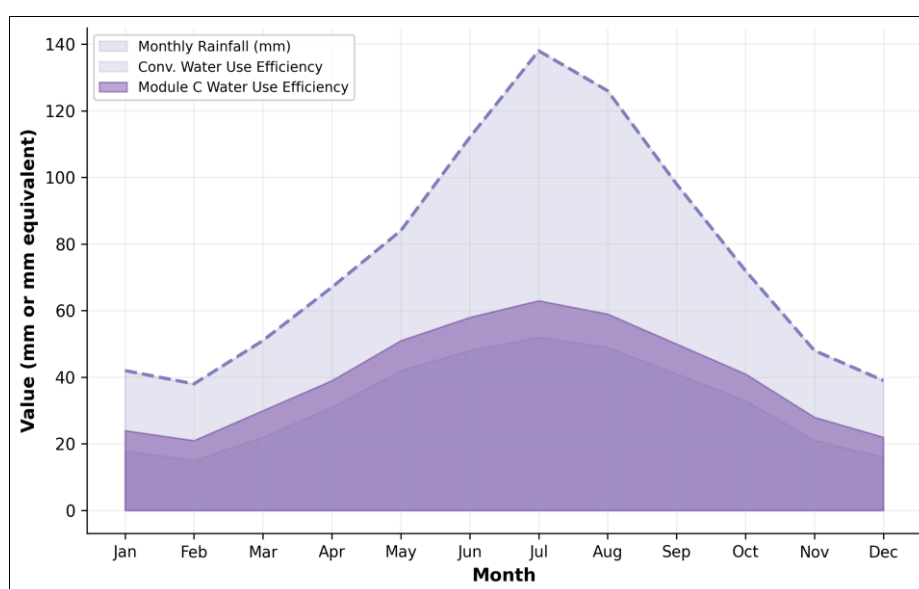


Fig2: Monthly rainfall distribution and comparative water use efficiency between conventional and Module C systems (three-year average)

Comprehensive interpretation

The progressive improvement from Module A through Module C confirms that layering complementary practices produces additive benefits. Intercropping alone provided moderate yield gains, but adding mulch and drought-tolerant cultivars together delivered the largest and most consistent improvements. The reduction in yield variability is especially relevant for rainfed farmers who bear the full risk of weather-driven fluctuations [18].

Discussion

The yield and stability gains observed with these modules are consistent with intercropping research from European field trials, though the magnitude of improvement exceeds most published comparisons. Bedoussac and Justes [5] reported 15-20% yield advantages for wheat-pea intercrops in southern France, while our Module A (intercropping alone) showed a 24.1% gain. The sandy loam soils of the Achterhoek region may amplify intercropping benefits because legume nitrogen fixation addresses the inherently low N-retention capacity of these soils [19].

The water use efficiency improvements deserve particular attention in the context of Dutch climate projections. Royal

Netherlands Meteorological Institute scenarios predict a 10-15% increase in summer drought frequency by 2050 [2]. Module C's 34.8% improvement in rainwater use efficiency provides a meaningful buffer against this trend. The combination of mulch reducing evaporative losses and contour furrows capturing runoff appears to create a synergistic soil moisture benefit that neither practice achieves alone [20].

Farmer satisfaction data add a dimension that purely agronomic trials often miss. The high adoption intent (83%) for Module C suggests that when farmers participate in designing and evaluating resilience strategies, they develop ownership of the results. But the 17% who weren't convinced cited concerns about labor requirements for mulch application and the upfront cost of new seed varieties. These barriers would need targeted policy support such as agri-environment scheme payments or equipment-sharing cooperatives to overcome at scale [21].

Conclusion

This three-year participatory research across 48 rainfed farms in the eastern Netherlands demonstrated that climate-resilient cropping modules can significantly improve yield, stability, water use efficiency, and soil health under temperate maritime

conditions. Module C, combining intercropping, conservation mulching, drought-tolerant cultivars, and micro-water harvesting, delivered the strongest results with a 27.3% yield increase and 34.8% improvement in rainwater use efficiency.

The participatory approach proved effective at generating both rigorous agronomic data and practical farmer feedback. High adoption intent among participants suggests these modules are compatible with commercial farming operations in the region. Reduced yield variability and improved net income offer tangible incentives for adoption, particularly as climate projections indicate more frequent drought episodes across northwestern Europe in coming decades.

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