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德国农业中的数字和智能技术

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1. 研究背景

本研究由德国莱布尼茨农业景观研究中心（Leibniz-Zentrum für Agrarlandschaftsforschung, ZALF）在德国研究与创新专家委员会（Expertenkommission Forschung und Innovation, EFI）的支持下完成。本研究提供了农业环境影响因素，以及德国农业中可商用的数字化和智能技术的清单、分类和评估。在本研究中，研究团队确定了目前可用于德国农业的数字和智能技术，并对其适用性进行了分类。他们将研究结果分为三个类别和十个子类别，包括用于数据收集的复杂系统、基于软件和硬件的技术，总共有 201 种商业技术（至 2023 年 3 月）。此外，他们还对特定国家的农业环境影响进行了盘点，并就数字技术在可持续性方面的障碍和潜力进行了在线调查，随后与农业、政策、工业、研究和民间社会等利益相关者进行了专家对话，并进行了文献综述评估。在此基础上，他们制定了进一步行动的关键建议，以克服障碍并促进德国农业可持续数字化的潜力。他们还提供了其他欧洲国家的最佳实践案例。他们的研究表明，迫切需要采取政策行动，在日常农场工作中更广泛地使用数字和智能技术来实现可持续性。

2. 现代农业遇到的挑战

- 为全球日益增长的人口提供食物与营养
- 保护环境
- 遵守政府法规
- 适应气候变化
- 有限的自然资源
- 增长的生产和劳动力成本
- 熟练劳动力短缺
- 不断增长的消费者需求

3. 研究方法

以下研究探讨了数字化和精准农业技术在可持续性和提高产量方面的潜力，以及它们对解决气候变化、人口增长、生物多样性下降、生态系统供应和产量波动等挑战所带来的粮食供应问题的贡献。为此，本研究基于四个工作包（WP）进行。这项研究于 2022 年 11 月至 2023 年 8 月期间进行。

工作包 I	目前德国农业中环境影响综述（文献综述 I）
工作包 II	识别德国创新性的精准农业和数字农业技术（文献综述 II）
工作包 III	评估已识别的创新性数字农业和精准农业技术 识别农业应用中的障碍（问卷调查、专家对话、文献综述（I+II））
工作包 IV	识别其他欧盟国家中数字技术应用的最佳实践案例

表 1: 本研究的工作模块

4. 德国农业中的环境问题

德国高投入农业对环境造成了显著影响。农业是德国温室气体（GHG）排放的主要来源之一（占 8.3%），德国农业还引发了其他严重的环境问题，例如地下水污染和生物多样性减少。为应对这些挑战，德国通过签署《联合国气候变化框架公约》、《京都议定书》以及欧盟关于排放限制和生物多样性指令等国际协议，承诺采取行动以减少这些负面影响。

4.1 农业气体排放及其对环境的负面影响

农业占德国温室气体（GHG）排放总量的近 8%，主要来自土壤耕作、氮肥使用和畜牧业，这些是甲烷（CH₄）和一氧化二氮（N₂O）的重要来源。2021 年，德国 65%的 CH₄排放和 77%的 N₂O 排放来自农业。过去 30 年间，农业温室气体排放量下降了 20.5%，主要原因是牲畜数量减少和化肥使用量下降。然而，由于生物沼气生产中的消化液导致氮肥使用量增加，2000 年代中期排放量曾暂时上升。

这些排放对环境的影响包括生态系统酸化、富营养化以及对人类健康的不利影响。德国根据《京都议定书》等国际协议承诺减少温室气体排放，并计划到 2045 年实现温室气体碳中和。然而，8%的农业排放数据并未包括上游部门（如肥料和饲料生产）的排放，这些可能会显著增加总排放量。农业排放的主要来源包括肠道发酵、粪污管理和土壤施肥。牲畜排放量基于饲料摄入量计算，其中粪污管理是一个关键因素。自 1990 年以来，排放量减少了 19.2%，主要原因是牲畜数量减少和合成肥料使用量下降。然而，近年来与生物沼气生产相关的氮肥使用量增加部分抵消了这一下降趋势。总之，尽管德国在减少农业温室气体排放方面取得了进展，但仍面临挑战，特别是在管理氮肥使用和解决农业上游活动排放方面。

4.2 农业氮污染及其对环境的负面影响

1961 年至 2020 年德国农业中肥料（氮、磷和钾）的总消耗量显示 1990 年左右使用量显著下降，主要归因于德国统一后新联邦州牲畜数量减少以及氮肥利用效率提高（作物产量增加和饲料转化率提高）。尽管如此，2020/2021 年德国农业仍使用了 190 万吨肥料（氮 126.5 万吨，

磷 19.2 万吨，钾 44.6 万吨），对环境仍是一个高输入量。此外，2019 年 3 月至 2020 年 2 月期间，德国农田和草地共施用了 2.09 亿吨粪肥。尽管肥料使用量总体呈下降趋势，但氮过剩负荷仍对环境造成负面影响，特别是水体等环境要素的氮过剩量仍超过临界阈值。1990 年至 2019 年，除马和羊外，其他牲畜的氮排泄量逐年增加。研究表明，尽管总体氮排泄量（以 kg N/ha 为单位）呈下降趋势，但在深垫料和消化系统中，氮排泄量显著增加。2020/2021 年，德国农业用地的氮输入量为 76 kg N/ha，仍高于国家可持续发展战略设定的 70 kg N/ha 目标值。总体而言，尽管德国在减少肥料使用方面取得进展，但氮过剩问题仍是农业可持续发展的重大挑战。

4.3 农业产生的磷污染及其对环境的负面影响

德国的农业，特别是畜牧业，对水体中的磷（P）污染贡献显著，导致波罗的海和北海等地区的富营养化。欧盟地下水指令为包括磷在内的污染物设定了阈值，德国通过国家监测网络对磷水平进行监控。目前，德国 67.3% 的地下水体化学状况良好，而 32.7% 的地下水体化学状况不佳，这些地区通常氮（N）过剩。2020 年的硝酸盐报告指出，过去 20 年中，河流和地表水中的磷污染有所减少，2019 年 43% 的监测点磷浓度低于目标值。然而，德国西北部一些地区仍显示出磷浓度上升的趋势。过高的磷水平会导致富营养化、氧气消耗和生态失衡，危害水生生物。尽管取得了进展，减少磷负荷仍然是一个关键的环境挑战。

4.4 农药污染及其对环境的负面影响

在德国，农药的销售和使用受欧洲及国家法律监管。2021 年，德国农药销售量为 28,945 吨活性物质，其中除草剂占比 50.6%。尽管农药主要用于农作物，但它们会进入周围生态系统，导致生物多样性丧失、蜜蜂死亡及水生生态系统破坏。研究表明，农药可能在土壤中长期残留，并扩散至地下水和水体，甚至进入自然保护区。农药污染还会影响物种适应能力，导致昆虫和两栖动物种群减少。农田边缘的缓冲带能有效防止农药进入附近水体，且缓冲带越宽，防护效果越好。尽管技术在减少农药使用方面具有潜力，但农药污染仍是严峻的环境问题。

4.5 德国农业生物多样性情况

自然生物多样性和农业生物多样性对农业土壤的功能和生产力至关重要，支持自然害虫控制、授粉和生物质循环等生态系统服务。然而，全球生物多样性正在下降，德国也不例外，农业集约化是主要原因之一。过去 30 年，德国自然保护区的昆虫生物量减少了 75%，草地昆虫生物量和物种数量也显著下降，这对食物链和植物授粉产生了严重影响。此外，农田野生植物物种数量也在减少，尤其是草本植物。为应对生物多样性丧失，欧盟和德国政府采取了多项措施，如欧盟共同农业政策中的“绿化”措施和德国农业结构调整与海岸保护联合任务（GAK）。德

国还实施了多项国家战略，包括植物、动物和水生遗传资源的保护计划，以及“未来资源、农业与自然保护”（F.R.A.N.Z.）项目，旨在促进农业景观中的生物多样性保护。这些努力旨在平衡农业生产与生态保护，减缓生物多样性下降趋势。

4.6 德国土地资源

土地是一种有限且稀缺的自然资源，尤其是在德国这样人口密集的国家。集约化农业与自然保护和资源利用之间的冲突尤为突出。鉴于土地稀缺和集约化农业对生物多样性和物种多样性的负面影响，德国政府在其可持续发展战略中制定了生物多样性和景观质量指标（基于鸟类指数）。影响农业产量的因素包括天气条件、草地的使用强度（如割草频率、施肥和动物放养率）等。传统农业与有机农业的使用方式也会影响农业用地的状况。2010 年至 2020 年的数据显示，德国用于有机农业的土地面积从 6% 增加到 10%，有机农场数量增长了 58%。看 2010 年至 2020 年德国各州有机农业用地的发展情况，整体呈现显著增长趋势，其中超过一半的有机农场集中在巴伐利亚和巴登-符腾堡州。

5. 农业数字技术

5.1 农业主要数字技术

自 20 世纪末以来，一些大型农场开始采用现代技术控制杂草，因为传统技术耗时且劳动力成本较高。这些技术包括机器人、传感器、无人机或地面车辆系统（无人机）、数字参考工具、数字农业机械和农场管理信息系统（FMIS）。农业数字化是指应用新的信息技术创造农业价值，并以优化农业流程为核心。尽管一些机构将“农业 4.0”、“精准农业”（Precision Farming, PF）和“智能农业”（Smart Farming, SF）等关键词视为同义词，但在实践中它们的定义和层次有所不同。农业数字化的趋势在科学、政治和其他领域的讨论中被不同利益相关者从不同角度描述和概念化，因此研究和行业中使用的趋势定义和概念并不总是清晰一致。因此，农业 4.0、精准农业和智能农业必须在利益相关者多样性的背景下加以理解和区分。本报告中提到的许多数字技术并非全新，事实上，许多概念早在 20 世纪 80 年代就已出现并持续发展。然而，特别是在过去 10 年中，农业数字化得到了显著推动，许多商业化技术得以广泛应用。在本研究中，本研究并未将这三个趋势等同，而是根据它们在农业中的功能范围进行区分。主要原因在于这三个趋势的目标不同，尤其是可持续管理和自然保护并未被定义为每个趋势的主要目标。

精准农业（Precision Farming, PF）是通过新技术应用改进农业管理的实践，利用特定地点和植物种群数据实现高效作物生产。它起源于 20 世纪 80 年代，旨在应对农田规模扩大和管理需求。精准农业通过智能系统结合信息获取、分析和投入应用，优化田间生产效率，比传统

方法更资源高效。精准农业专注于经济激励，环境和社会因素常被忽视。如今，“精确农业”已成为更常见的术语，取代了“精准农业”在学术文献中的使用。

智能农业 (Smart Farming, SF)： 智能农业不仅包含精准农业 (PF)，还通过扩展数字技术的应用范围，连接农场内的不同“子领域”，帮助农民将来自数据生成设备网络的信息与执行设备在物联网 (IoT) 中整合。这一过程不仅生成空间相关数据，还产生大量实时和特定情境的数据，从而实现流程自动化。因此，精准农业可被视为智能农业的一个子类别。智能农业与物联网 (IoT) 密切相关，物联网通过嵌入式技术实现传感器等数据生成设备与软件技术的通信和计算，为智能农业提供关键支持。智能农业通过更精确和资源高效的方式，有望支持更具生产力和可持续性的农业。目前，欧洲仅五分之一的农民日常使用智能农业技术，而美国高达 80% 的农民使用智能农业工具进行作物生产。2019 年，欧盟理事会正式认可了智能农业在可持续数字未来中的潜力。

农业 4.0： 农业 4.0 是一个正在改变农业生产能力的行业趋势。通过将大数据、人工智能和数字技术应用于实践，它能够收集和处理来自所有农田的数据，帮助农民优化田间管理。这一趋势始于 2010 年左右，旨在提高生产力、合理分配资源并适应气候变化，有望带来全球性的重大改进。在学术文献中，新术语“农业 5.0”已开始出现。农业 5.0 是下一阶段的行业趋势，同样使用传感器、大数据、物联网、机器人和人工智能，但其应用范围更广。例如，田间机器人可以区分作物和杂草，甚至识别不同杂草种类。农业 4.0 预计将显著改变农民的工作性质和劳动就业，因为它提供了节省劳动力的技术。

5.2 复杂的数据处理系统

目前农业领域可获取的数据种类与规模日益增多，包括卫星图像、联网传感器以及监测系统。为了让这些海量而复杂的数据在农业生产中真正发挥作用，需要依赖机器学习 (ML)、人工智能 (AI) 和大数据 (BD) 等复杂的数据处理系统。机器学习和人工智能是许多软件型农业技术的核心，但算法设计主要由计算机和数学专家完成，农民则只需提供数据输入。在日常生活中已有多项基于 AI 的线上工具（如 ChatGPT、DeepL 等），但能直接为农民所用的 AI 工具目前还比较有限。实际上，大多数辅助决策的农业技术都内置了 AI 功能，只是厂家往往并未在产品介绍中明示。大数据则进一步整合并高速处理多源异构数据，与 ML 和 AI 结合，用于预测分析和商业智能。硬件技术（例如传感器）会采集环境信息，通过软件技术传递给 ML 和 AI，再在农场管理信息系统和决策支持系统中转化为实际建议。由此，软件与硬件、算法与数据的多重结合，为农业提供了更精准和可持续的生产与管理模式。

机器学习 (Machine Learning, ML) 并不等同于人工智能，而是其前置阶段，通过算法对训练数据进行分类。ML 描述了从硬件收集数据到在更复杂的 AI 或大数据场景中使用这些数据

的整个学习过程，其核心过程被称为“训练”。最早的 ML 方法出现在 20 世纪 50 至 70 年代，主要用于描述和分类数据，采用了决策树或逻辑公式等方式。现代的决策 ML 模型包括回归、聚类、概率图模型、记忆模型、决策树、人工神经网络（ANN）、支持向量机以及集成学习等多种方法。深度学习（DL）常与 ML 一同使用，它标志着人工神经网络向更深层次神经网络（DNN）的演进，拥有更强的学习能力。在 ML 的层级中，DL 处于较低层次，而 ANN 由于其灵活性被广泛应用于各类 ML 任务，且 ML 算法通常比 DNN 的结果更易解释。研究显示，在 2011 至 2020 年期间，“机器学习”是农业相关学术文献中第二常用的术语，且全球范围内玉米和小麦是被 ML 模型研究最多的作物。总的来说，机器学习是数字农业技术中不可或缺的一部分，但其开发和应用主要由技术专家负责，农民仅作为终端用户提供必要的数据输入。

人工智能（Artificial Intelligence, AI）：近年来，全球农业中大量采用了基于 AI 的解决方案，这些技术通常嵌入在软件中或用于农业预测。由于这些 AI 解决方案并非专为农民设计，其直接在农业中的应用相对有限。文中区分了“AI 驱动”与“基于 AI”的技术：前者由 AI 生成功能或建议，而用户只能使用最终的软件产品；后者则允许农民直接使用，甚至参与学习过程。例如，NVIDIA 的深度学习 AI 软件可开发出用于边缘计算的芯片，并安装在田间机器人上，使其成为 AI 驱动的设备，而农民只接触成品。此外，AI 驱动芯片能够独立于服务器和云端运行，与其他软件技术形成区别。“There’s an AI for That”平台显示，目前有 3600 种农场管理软件的 AI 解决方案，涵盖 609 项任务，如自动化、健康监测和产品推荐等。比如 agriGPT 和 heliopas.ai 的基于 AI 工具，使农民能够直接获取包括土壤均质性、湿度、作物类型和健康状况在内的快速数据分析结果。

大数据（Big Data, BD）能够实时整合农业生产的各种信息，为农民提供更智慧的决策依据。该术语于 2015 年前后在科学领域兴起，与当时迅速增长的数据生成量密切相关。德国联邦教育与研究部（BMBF）已在柏林和德累斯顿建立了两家大数据能力中心，并计划于 2025 年设立专注农业食品生产的 AI 与 BD 中心。在农业学术研究中，“大数据”目前是第十常见的关键词，但其在农业领域的应用仍处于初步阶段。大数据的核心特征可用“3V”来概括：庞大的数据量（Volume）、多样性（Variety）以及高速（Velocity），并可进一步扩展至更多“V”指标，如数据真实性（Veracity）。由于农业生产中涉及庞大且异质的数据，大数据处理不仅需要高度的实时性和准确性，还需要考量社会与伦理层面的影响。目前，大数据主要被应用于预防食品安全风险、开发田间机器人以及优化作物产量预测等方面。在应对气候变化的背景下，大数据分析对农业的短期和长期预测都具有重要意义，但依旧面临伦理、文化、政治和生态等多重挑战。展望未来，大数据将在农业数字化转型和可持续发展中发挥越来越关键的作用。

5.3 软件技术

软件型农业技术主要基于云计算理念，通过远程服务器提供按需使用的 IT 资源。常见的数据格式包括 Shapefile (.shp) 和 ISO-XML，前者用于存储地理要素位置与属性，后者则用于农机终端与农场管理软件间的数据交换。本研究将软件型技术分为四大类：

- 农场管理信息系统（FMIS）和决策支持系统（DSS）：基于物联网，利用各类数据（如传感器信息）进行农业过程优化；
- 驾驶与操控数字技术（DTGS）：基于全球导航卫星系统（GNSS）实现精准半自动驾驶和农机控制；
- 数字信息平台（DIP）：用于数字化协作、联网及知识共享，可为更高层级的软件（如 FMIS 和 DSS）提供数据；
- 公民科学（CS）应用与平台：可收集并提供大量数据，助力机器学习算法的开发和完善。

农场管理信息系统（Farm Management Information System, FMIS）和决策支持系统（Decision Support Systems, DSS）

农场管理信息系统（FMIS）是一种基于物联网的技术，通过整合各类数字技术产生的数据来优化农业行政和运营流程。由于需要综合分析产量、施肥量、植保投入、机器数据及土壤信息等多方面数据，FMIS 通常会采用机器学习方法。与学术界更注重复杂系统分析不同，商业化 FMIS 主要面向农场管理与运营规划，并在 2010 年后逐渐进入市场。德国农场平均经营规模为 63 公顷，但由于 FMIS 的成本和复杂度较高，目前尚未在小型农场得到广泛应用。当 FMIS 将数据采集与处理功能应用于田间层面的管理决策时，就演变为决策支持系统（DSS）。FMIS 偏重整体农场运营（包括作物、畜牧、机械管理、薪资及空间与时间管理等），而 DSS 则侧重为生产过程中的决策者提供信息支持。一些研究者将 FMIS 视为可记录大量农场数据并用于决策的工具，但本研究坚持 FMIS 的原始定义，将“电子田间日记”或数字田块索引等软件归为 DSS。市场上大部分 FMIS 和 DSS 都以移动或网页应用的形式出现，需要付费才能使用更多高级功能。合作研发的免费 DSS（如 CropSAT、EcoPay）功能较为简化，而像 Magic Scout 这样的免费工具也只能提供有限的功能模块。NEXT Farming 等公司还提供与 FMIS 相配套的硬件气象站，以进一步提升农场数据采集的精确度。欧盟资助的 FAIRshare 平台能帮助农场顾问基于不同应用需求搜索合适的数字工具，并给出具体建议。具体案例方面，CLAAS TELEMATICS 是一款 DSS，可与 365FarmNet 平台对接并提供多种付费授权，而 365FarmNet 本身也为用户提供了从免费基础模块到定制化模块的多种选择。

数字制导与转向技术 (Digital technologies for Guidance and Steering, DTGS)

DTGS 是精准农业的先驱，在作物种植中应用最广泛。其功能基于全球导航卫星系统 (GNSS) 的空间数据，帮助农民通过精确驾驶和操控优化田间作业。调查显示，在德国巴伐利亚州，最常用的数字技术包括自动驾驶系统 (30%)、基于 GPS 的技术 (21%)、卫星地图数据 (18%) 和光学导航工具 (11%)。DTGS 主要用于半自动化的机器引导和操作，以减少驾驶员的工作负担并提高作业精度。其数据来源包括传感器、卫星、无人机和 FMIS/DSS，能够实现精准施肥和农药使用，提高资源利用效率。然而，过度精准可能带来生态风险，例如边缘地带缺乏足够的动植物栖息地。与其他数字技术相比，DTGS 软件的购置成本较低，部分服务甚至可免费提供。

数字信息平台 (Digital Information Platforms, DIP)

FAO 指出，共享知识是实现农业生态目标的关键因素之一。知识共享在可持续农业的设计中至关重要。DIP 为农民提供正式和非正式教育，并促进食品系统中的协同作用。在数字工具的开发和数据收集分析过程中，不同利益相关者之间的协调与沟通至关重要。除了技术整合能力，DIP 还作为不同利益相关者之间的中介，例如在供需关系中发挥作用。通过在商业环境中协调各方行动，DIP 能创造新的经济价值。DIP 作为农业价值链交易的中介，对可持续农业的设计具有重要意义。

公民科学平台和应用 (Citizen Science platforms and applications, CS)

公民科学平台 (CS) 指公众积极参与科学研究任务，这一概念具有灵活性，可适用于不同学科和情境。CS 的趋势始于 1990 年代，最早的显著案例出现在奥地利、德国和西班牙，并在农业等自然科学领域带来了长期的社会效益。CS 平台和应用程序促进创新和学习，同时作为科学研究的重要数据来源，并且通常可免费访问，志愿者无偿参与数据收集。2015 年，欧洲公民科学协会 (ECSA) 制定了 CS 的关键实践原则，包括成果、参与度、数据问题和研究方法等方面。CS 数据主要以图像、声音和短片的形式呈现，并通过地理标记照片或智能手机位置信息进行空间定位。公民科学的数据收集能够覆盖难以到达的地区，提供更密集和更频繁的观察，适用于监测农业生产、土地利用变化和生物多样性影响。近年来，科学界逐渐认识到 CS 数据的潜力，但目前仍较少出现在同行评审的学术论文中。CS 依赖一定的资金支持，并需要专家监督数据处理和与数据收集者进行有效沟通。在德国，知名的 CS 项目由专家指导，例如由联邦自然保护局资助和管理的 Deutschlandflora 和德国红色名录中心 (RLZ)。另一个著名的 CS 平台是德国自然保护联盟 (NABU)，它提供 Naturgucker 应用程序，组织公众观察活动，并推动有关刺猬和鼯鼠等物种的数据收集。

5.4 硬件技术

硬件是数据处理系统的物理组成部分，与软件相辅相成，包括电容、电路板、设备、鼠标、键盘、显示屏、打印机及存储设备等。本研究中的硬件技术分为三类：传感器（S）、田间机器人（FR）和无人机（UAV）。传感器是用于收集环境信息的物理设备，可用于农业测绘和数据采集，既可固定（如卫星），也可移动，以测量温度、湿度、降水量、光照强度等。田间机器人是半自主或自主机器，通过编程执行农业生产任务，利用传感器和人工智能感知环境，并能在田间自主决策，例如用于作物除草。无人机是由人类控制的半自主或自主飞行器，内置计算机，可用于监测、图像采集、激光测量等多种任务。无人机可与工具和传感器结合，实现喷洒、播种、种子和物资运输、监视、3D 建模及声学记录等功能。所有硬件技术均需要付费，其价格因制造商和附加功能不同而变化。田间机器人可配备摄像头、传感器、除草工具、喷洒设备，甚至电击装置等。无人机也可搭载摄像头、传感器、喷洒设备和运输工具，以满足不同农业需求。硬件技术在农业中的应用正在不断拓展，为农业生产提供更高效和精准的解决方案。

传感器（Sensors）： 传感器是一种通过观察收集信息的设备，可用于农业区域的固定测绘和评估。传感器通常与机器人技术结合使用，以提高农业管理的精准度和效率。作为移动工具，传感器可减少化肥和农药的使用，并用于测定饲料质量特征。多光谱图像传感器有助于监测和评估农业生态系统的状况。被动传感器反射阳光，无法自行发射辐射，其测量范围主要在可见光和红外光谱内。主动传感器能发射和接收辐射，主要在微波范围内工作，可用于优化氮肥供应。通过感知植物的光反射情况，传感器可指示植物的叶绿素供应状态，帮助精准施肥。研究中仅实施了少量虚拟围栏技术实例，这种技术对动物福利及生态系统均有积极影响。虚拟围栏避免了传统围栏对野生动物的干扰，使其能够按照自然习性自由活动。牲畜的自由放牧有助于塑造更自然的景观，减少人为农业活动对环境的集中影响。

田间机器人技术（Field Robotic Technologies , FR）

田间机器人是根据欧洲机械指令定义的农业半自主或全自主机器，可执行农场生产任务。这些机器人利用传感器和人工智能（AI）技术来感知环境并做出决策，提高农业效率。农业机器人主要有两种发展路径：现有技术自动化和开发新型小型机器人。目前，农业机器人在奶牛养殖中应用较多，如挤奶机器人和健康监测机器人。田间机器人主要用于作物生产，特别是利用机械或化学方法控制杂草。一些新兴方法，如热控和电控除草，正在开发自动化解决方案。田间机器人仍需优化，以适应大规模农场的需求，主要挑战包括工作速度和作业面积。目前机器人的作业速度为 1-4 km/h，其除草效果因土壤类型和杂草密度等因素而异。田间机器人还可用于采摘水果、移栽幼苗、授粉、修剪和农场运输等任务。目前关于田间机器人功能和结构的学术研究不断增加，但大多仍处于概念或实验阶段。预计未来 10 年内，田间机器人将在农

业生产中更加普及。研究中共识别出 31 种商业田间机器人，但 93%的农民仍未计划购买。例如，FarmDroid 的 FD20 机器人通过 GPS 精确播种和除草，而不依赖摄像头或传感器。其他机器人，如 BoniRob、Robovator、Robocrop InRow Weeder 和 OZ 除草机器人，采用不同技术实现精准除草和农作管理。

无人机 (Unmanned aerial vehicles, UAV) 和无人飞行系统 (unmanned aerial systems, UAS)

无人机 (UAV) 或无人飞行系统 (UAS) 是一种数字技术，可以由人远程控制或由内置计算机半自主运行。根据欧盟 2019/947 法规，无人机系统包括无人驾驶飞机及其远程控制设备。无人机的尺寸差异较大，反应速度快，其基本结构包括一个轻质框架，并可根据发动机数量分类，如双旋翼 (2 个引擎) 或八旋翼 (8 个引擎)。与其他技术相比，无人机更加便捷且成本较低，适用于作物种植监测和农业决策支持。无人机可用于空中运输物资，并结合高清图像处理、目标识别和模式分析技术进行数据采集。在农业领域，无人机最重要的用途是杂草检测、制图和管理，提高精准农业水平。其他应用包括作物生长监测、产量预测及植物健康状况评估。过去十年间，无人机在农业中的应用逐渐多元化，涵盖多个领域和用途。尽管农业无人机技术发展迅速，但目前关于其应用的学术综述较少。无人机技术的发展为农业提供了高效、精准的作业方式，有望进一步提升农业智能化水平。

6. 研究结果

6.1 研究对象人口结构

调查结果显示，本研究大多数参与者 (38.3%) 来自研究机构，其次是农民和政界/行政部门的雇员 (各占 18.3%)。紧随其后的是来自其他公司/行业 (13.3%) 的参与者。

本研究询问了参与的农民、农业服务供应机构的雇员和“其他”类别的参与者他们活跃于哪个农业部门，允许多个答案。耕作是最具代表性的农业部门 (35.1%)，其次是草地管理 (27%) 和畜牧业 (24.3%)。这些利益相关者群体中只有少数参与者报告说他们活跃于园艺和其他领域。

研究结果显示，本研究参与者中有机农业 (42.9%) 是主要的经营模式，此后是减少使用化肥和农药的传统农业 (35.7%)。最少提到的经营模式是经典的传统模式 (24.1%)。

为了进一步对参与调查的农民及其农场结构进行分类，本研究要求他们说明他们目前管理的农田总面积。结果显示，小规模 (≤ 100 公顷) 和大规模 (> 100 公顷) 农场的分布几乎相等。最常见的规模是 201-500 公顷和 $> 1,000$ 公顷 (各占 21.5%)，其次是 101-200 公

顷、501-1,000 公顷和 < 5 公顷（各占 14%）。最不常见的规模是 51-100 公顷和 21-50 公顷。

研究对象中德国各联邦州的农场分布情况结果显示，大多数（58%）农场位于萨克森州。其他代表性的联邦州——巴登-符腾堡州、勃兰登堡州、黑森州、下萨克森州、北莱茵-威斯特法伦州和萨克森-安哈尔特州——各占 8% 的农场。

为了对参与的研究人员和政治/行政部门、协会、非政府组织和工业界员工的工作和专业知识进行分类，本研究询问他们在他们所指出的重点领域工作了多长时间。这些群体的大多数利益相关者（59%）在各自的重点领域工作了 10 年以上，其次是 2-5 年（18%）、6-10 年（18%）和不到 1 年（6%）。

关于 60 名参与者的个人人口统计特征，本研究首先询问他们的性别。结果显示，70% 的参与者认为自己是男性，18.3% 认为自己是女性，1.7% 认为自己是其他性别，10% 没有回答。调查结果显示，56-66 岁年龄段的受访者人数最多（43%），其次是 25-35 岁（18%）、46-55 岁（18%）、36-45 岁（16.5%）和 66 岁以上（1.5%）。对于最后一个人口统计问题，本研究询问了受访者在调查时所拥有的最高学位。45% 的受访者拥有博士学位，其次是本科（20%）、硕士学位（20%）、专业学校学位（5%）、职业培训（3%）、学士学位（3%）或其他学位（3%）。

图 58 显示，利益相关者群体中最普遍和最常使用的技术是农业机械数字技术 - 执行器技术，该群体中有 36% 的参与者每天或定期（每周）使用这项技术。第二大使用技术组是检测和传感器技术 - 传感器技术（每天：21%；定期：0%；偶尔 [每月]：7%）。其次是 FMIS/DSS（每天：7%；定期：29%；偶尔：7%）和 DIP（每天：0%；定期：21%；偶尔：14%）。最少使用的数字和智能技术包括 CS 平台（79% 既未使用也根本不打算使用）、无人机和系统（64% 既未使用也根本不打算使用）和田间机器人（64% 既未使用也根本不打算使用）。然而，与田间机器人相比，无人机和空中系统似乎更受欢迎：7% 的人表示经常使用，14% 的人表示偶尔使用。

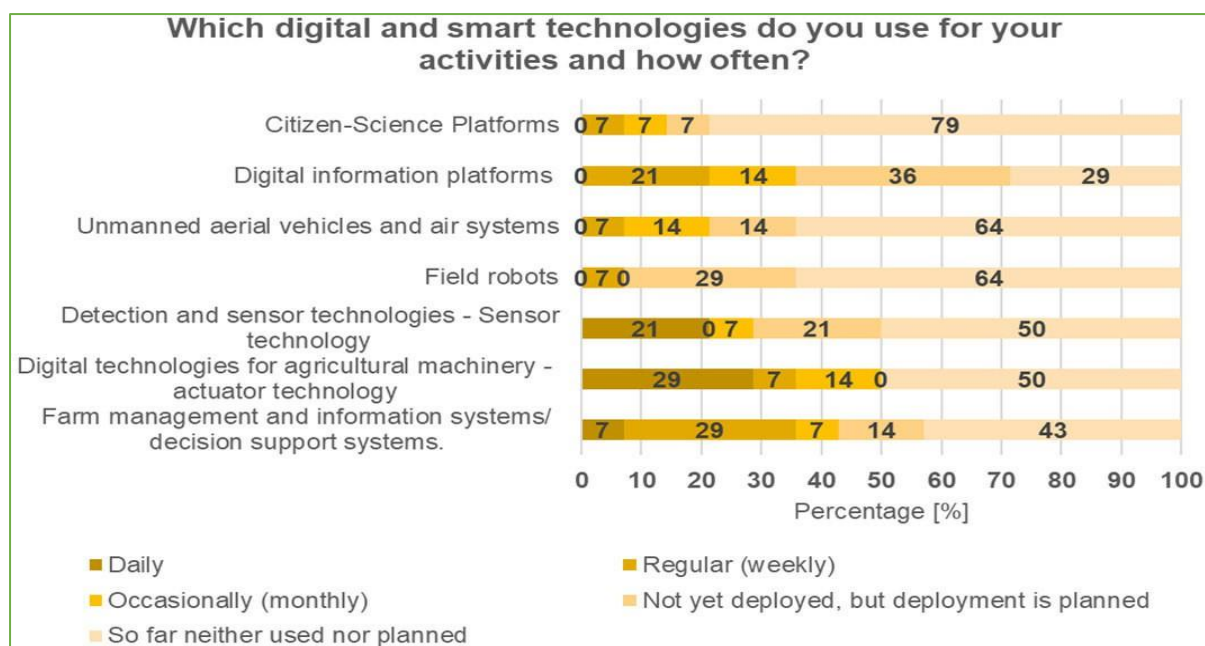


图 58: 不同利益相关者的数字农业使用频率

图 59 显示，最常见的应用领域是田地监测和改进运营管理（92%）。第二大应用领域是实施环境保护法规（83%）。其他已经频繁使用上述技术的领域包括减少环境有害物质的传播（75%）、数据和知识的传输（67%）以及通过数据驱动的分析支持决策（67%）。数字和智能技术在土壤结构改善以及生物多样性促进和保护方面的应用最少（58% 的人对每个类别都表示没有）。

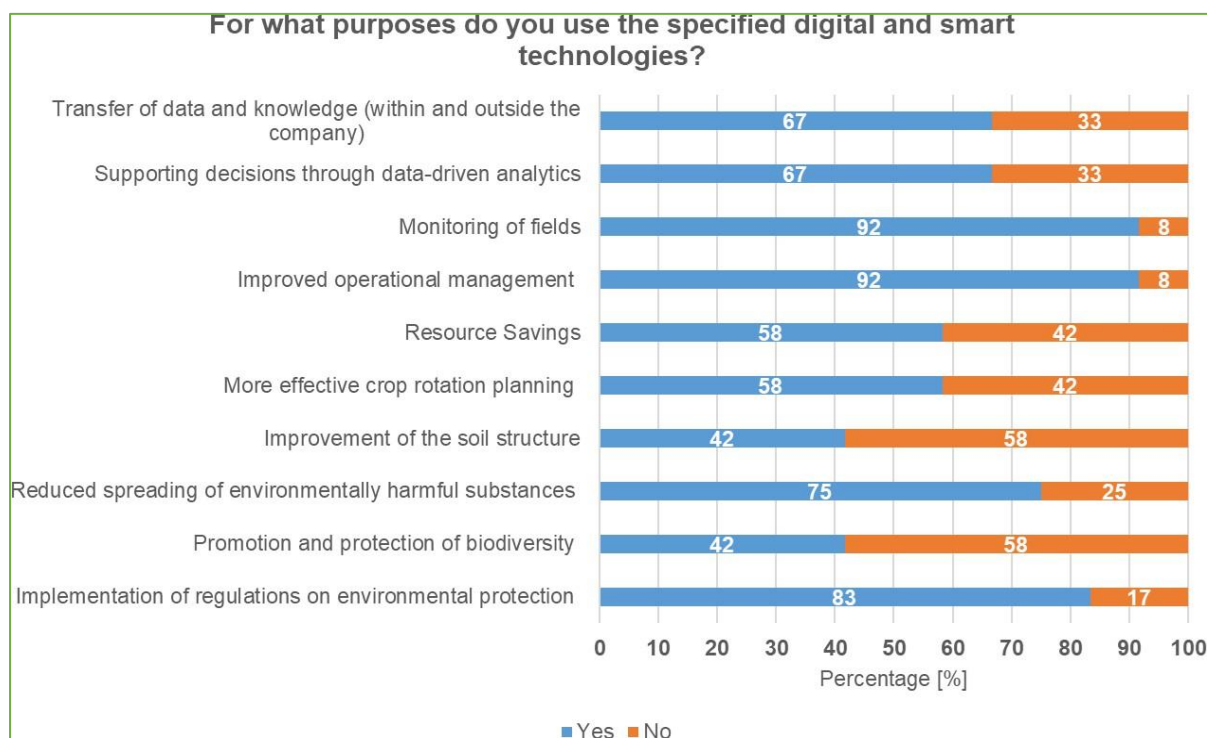


图 59: 不同利益相关者使用数字农业的目的

数字和智能技术最大的两个贡献是节约资源和减少使用对环境有害的物质（各占 60%）（图 60）。其次是通过数据驱动的分析支持决策（53%）、田地监测（40%）以及数据知识转移和改善农场管理（27%）。数字和智能技术最小的贡献是改善土壤结构（完全没有贡献：7%；贡献很小：67%）。同样，对更有效的轮作计划的贡献也很小（完全没有贡献：7%；贡献很小：47%）（图 60）。

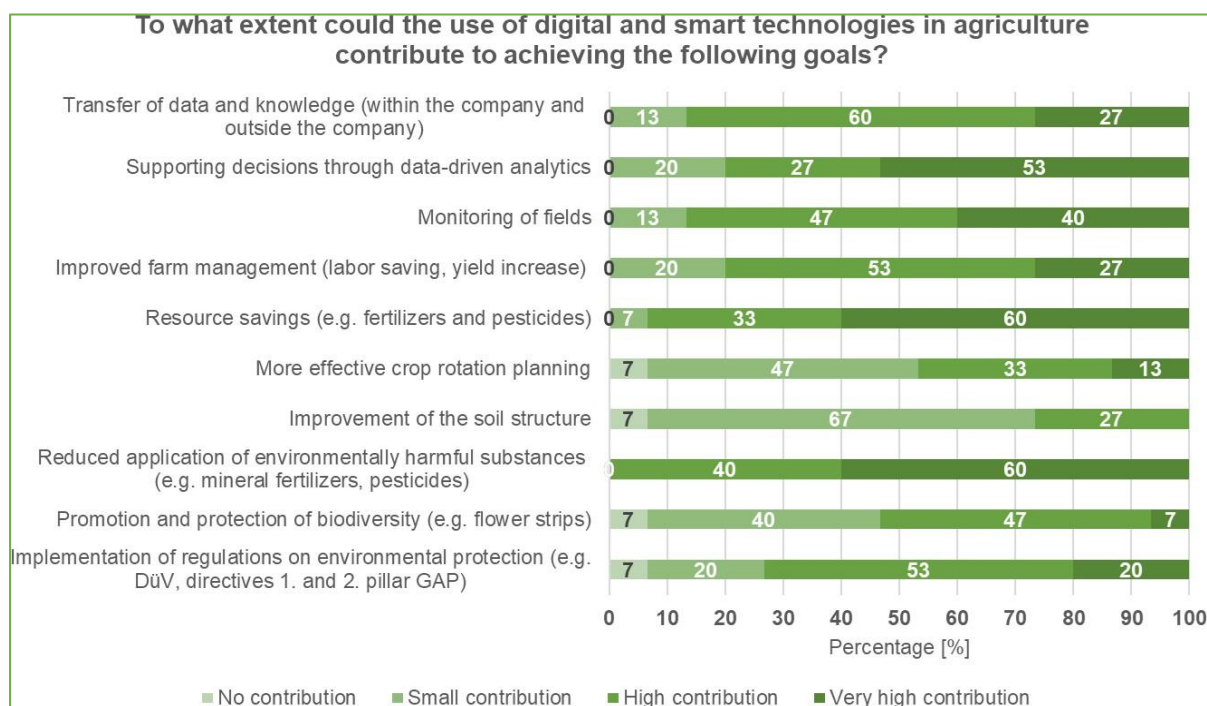


图 60: 不同相关利益者为实现目标的数字和智能技术贡献

图 61 显示，最发达（技术就绪水平 7-9：部署）的数字和智能技术是农业机械 - 执行器技术（77%），其次是 FMIS/DSS（65%）和记录 and 传感器技术 - 传感器技术（61%）。

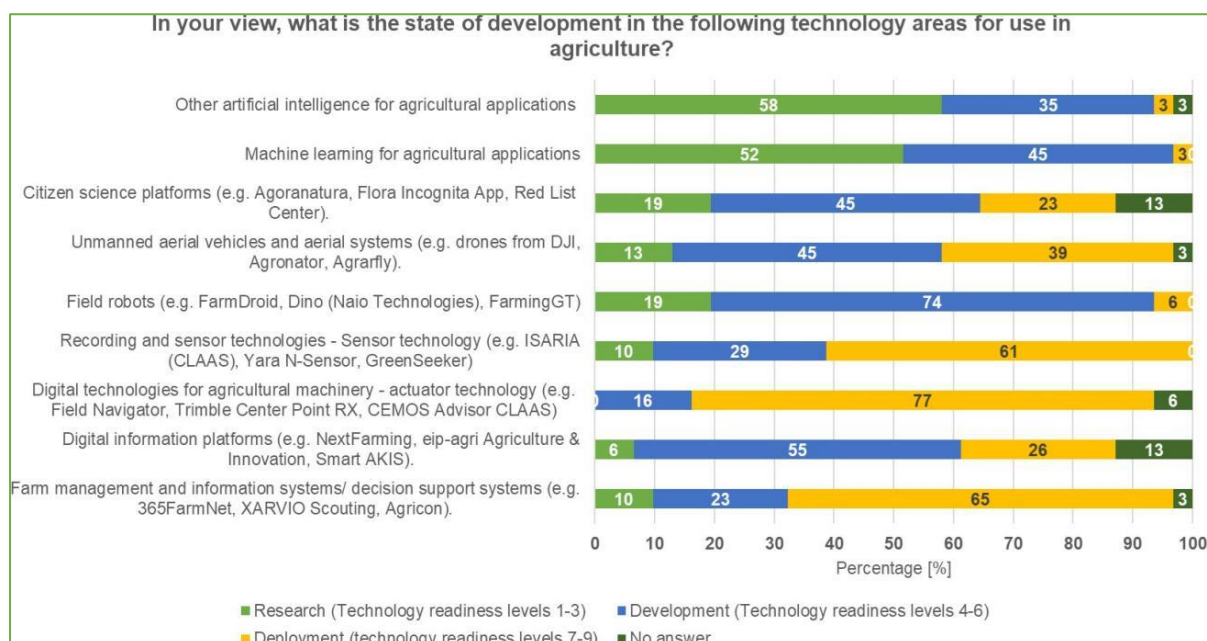


图 61: 利益相关者（研究和其他行业）分配的数字和智能技术发展状态

6.2 常规使用数字和智能技术的障碍

最大的阻碍因素是不同供应商的技术之间缺乏兼容性（非常大阻碍：29%；大阻碍：64%）（图 62）。其次是数字和智能技术的购置成本高以及网络连接不稳定（非常大阻碍：14%；大阻碍：36%）。

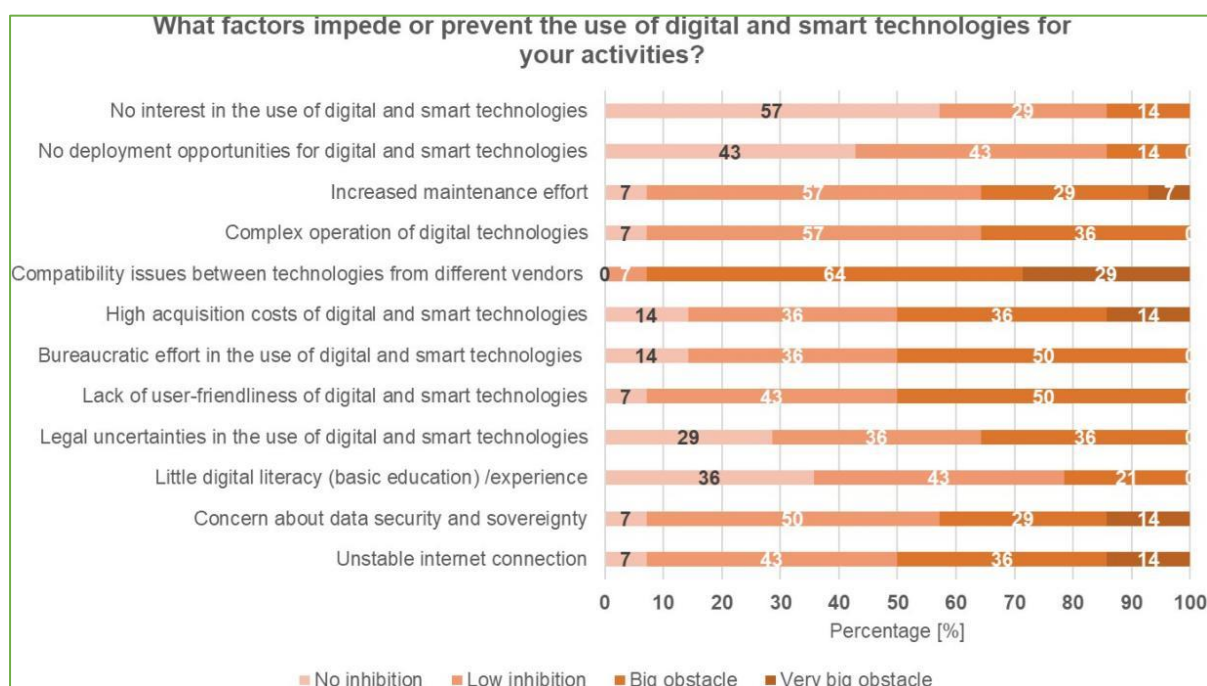


图 62: 利益相关者认为使用数字农业的阻碍因素

图 63 显示，与第一组利益相关方的回答类似，第二组利益相关方也认为兼容性不足是最重要的因素（非常大的障碍：50%）。第二重要的因素是网络连接不稳定（非常大的障碍：41%），其次是数据安全和主权问题（非常大的障碍：22%；大障碍：54%）、数字和智能技术缺乏用户友好性（非常大的障碍：41%）、数字和智能技术的高昂购置成本（非常大的障碍：15%）和官僚主义（非常大的障碍：15%）（图 63）。

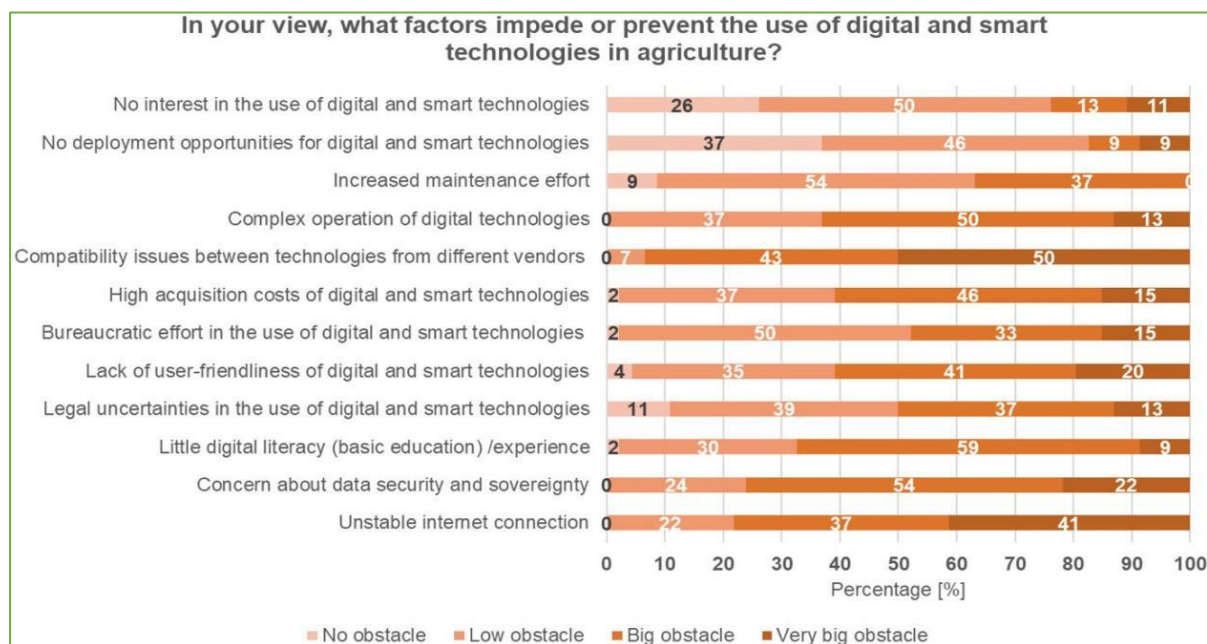


图 63: 利益相关者认为使用数字农业的阻碍因素

数字化和智能技术的潜力

图 64 显示了参与调查的农户、农业服务提供机构员工和“其他”类别参与者的回答。其中最重要的措施是引入数据和技术标准以提高兼容性（非常重要的措施：64%）。其次是明确的数据主权法律规定（非常重要的措施：50%；相当重要的措施：36%）；为中小型农场提供专门的支持计划（非常重要的措施：43%；相当重要的措施：29%）；以及咨询、教育和培训服务（非常重要的措施：36%；相当重要的措施：57%）。根据该利益相关者群体的说法，购买数字和智能技术的补贴对数字和智能技术的应用影响较小（非常重要的措施：21%；相当重要的措施：50%）。

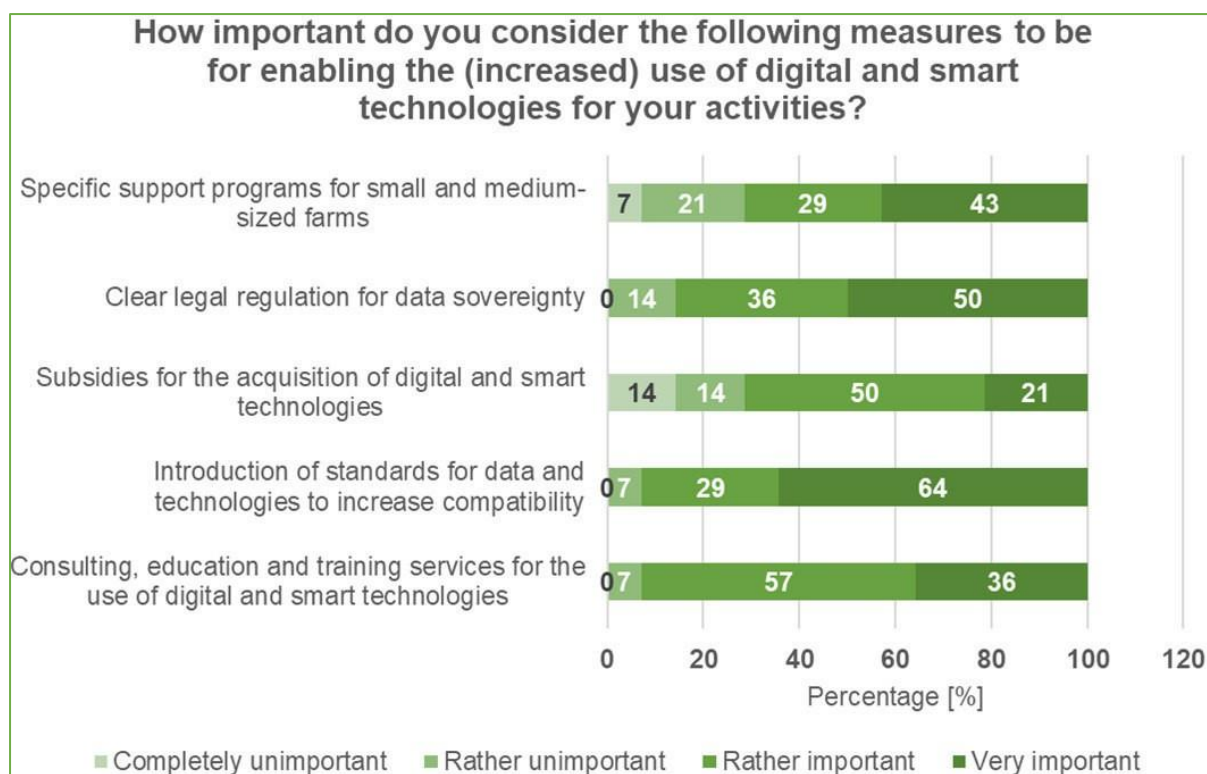


图 64: 利益相关者对怎样提高数字农业的看法

图 66 显示，数字和智能技术在提高效率方面潜力最大的领域是传统农业，因为传统农业减少了化肥和农药的使用，并且高度重视“良好农业实践”（极高潜力：43%；高潜力：42%）。其次是提高蔬菜种植效率（极高潜力：42%；高潜力：42%）、耕地种植（极高潜力：38%；高潜力：42%）、传统农业（极高潜力：25%；高潜力：48%；中等潜力：25%），最后是草地种植（极高潜力：10%；高潜力：23%；中等潜力：28%）。

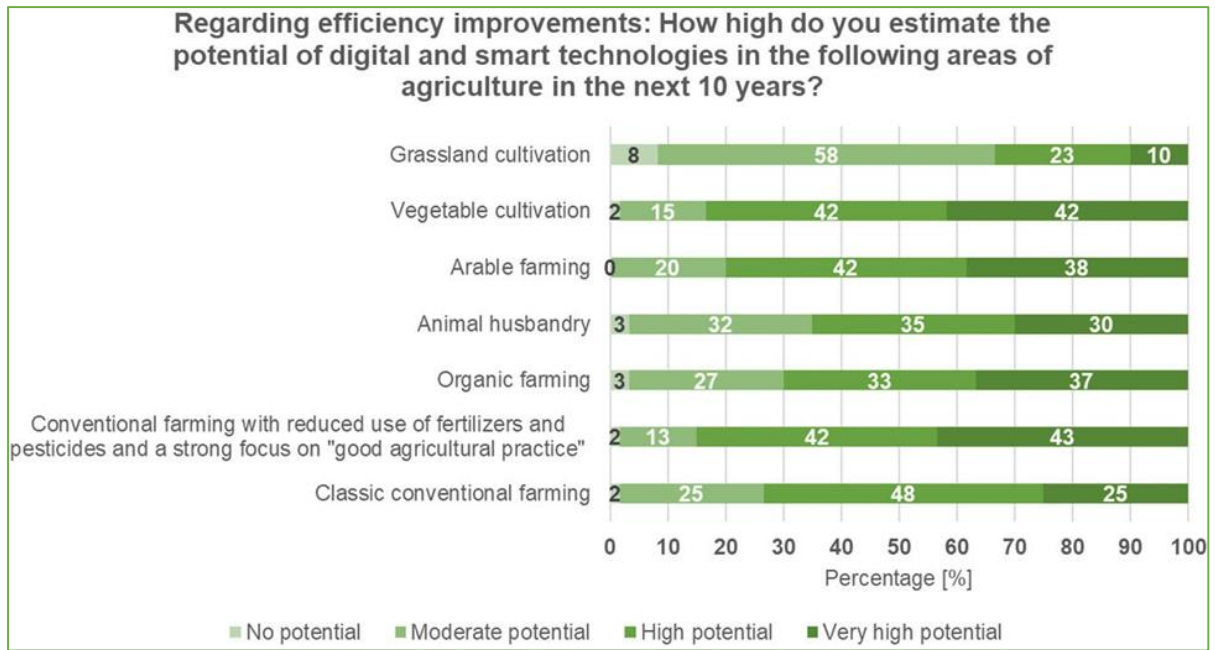


图 66: 利益相关者对如何提高数字农业的看法

7. 可持续农业数字技术和障碍评估

文献综述与见解

德国是全球现代技术生产和使用的领先国家之一，数字化有助于提升德国农业的竞争力。然而，数字化作为解决生态问题的目标尚未实现，未来的成功取决于农业、社会接受度以及经济和政治条件。负责任的技术创新需要广泛利益相关者的参与，但目前数字化转型主要集中在全球粮食安全、可持续集约化和气候智能农业上。有机农业、永续农业和再生农业的数字化未受到足够关注，因其产量潜力较低（图 74）。当前数字技术主要用于优化农业流程以提高产量，但也可能用于更广泛的可持续农业设计。无人机和田间机器人等新技术在可持续农业中显示出巨大潜力，但其发展方向仍受技术驱动。呼吁政策制定者开发可持续的农业数字化商业模式，而非仅关注经济效益。

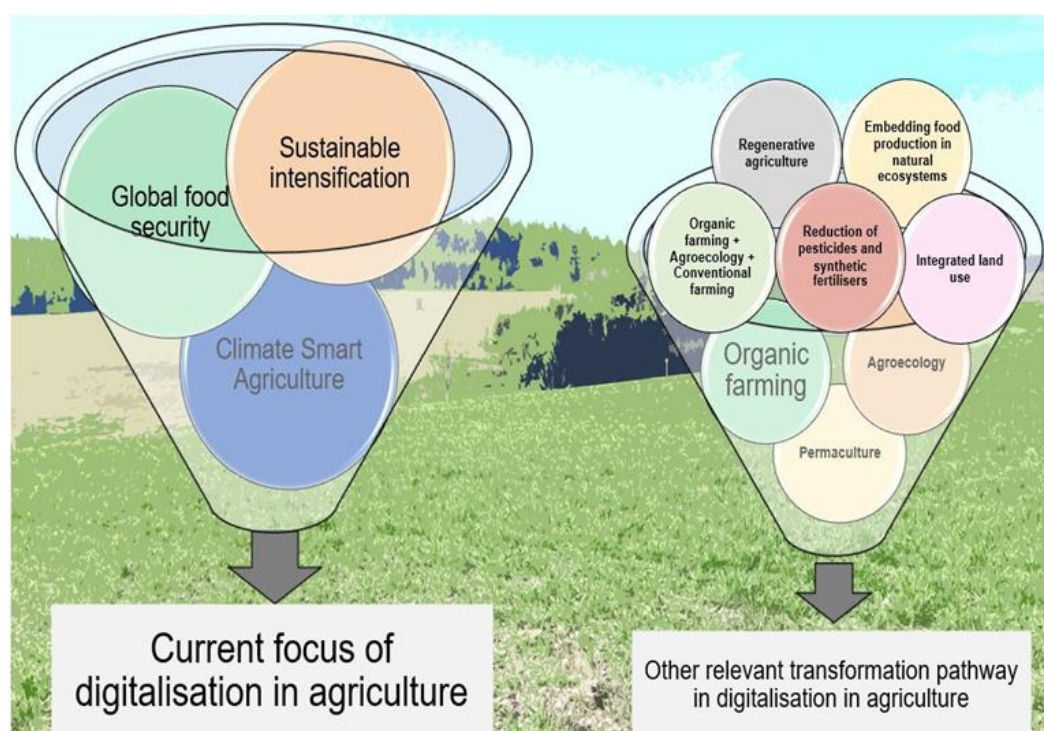


图 74: 可持续农业的可能转型路径与当前农业数字化重点

潜力

当前数字技术主要用于优化农业流程以提高经济效益，但也可能用于更广泛的系统监测。数字技术为不同利益相关者之间的协调提供了新机会，并有助于提高资源利用效率和减少温室气体排放。无人机和田间机器人等新技术在可持续农业中显示出巨大潜力，特别是在自然保护方面。技术发展主导了技术应用方向，但在气候变化和生物多样性减少的背景下，这种模式需要改变。政策制定者应推动可持续的农业数字化模式，而非仅关注经济效益。数字技术的应用

需要更多关注生态和社会效益，而非单纯的技术进步。通过数字技术实现农业的生态转型需要多方合作和政策支持。

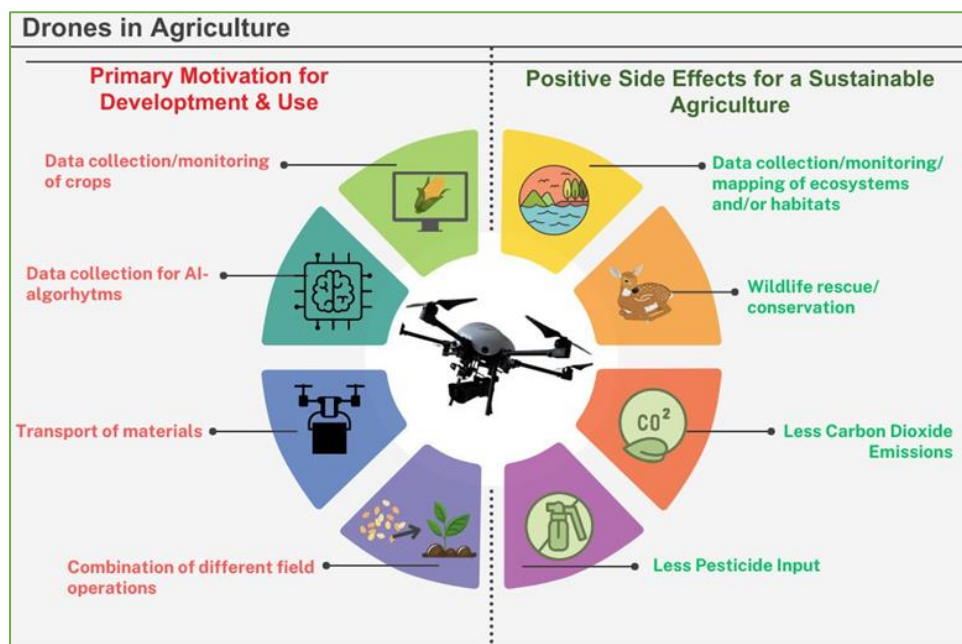


图 75: UAV/UAS 在农业领域开发和使用的主动机及其对可持续农业的积极影响

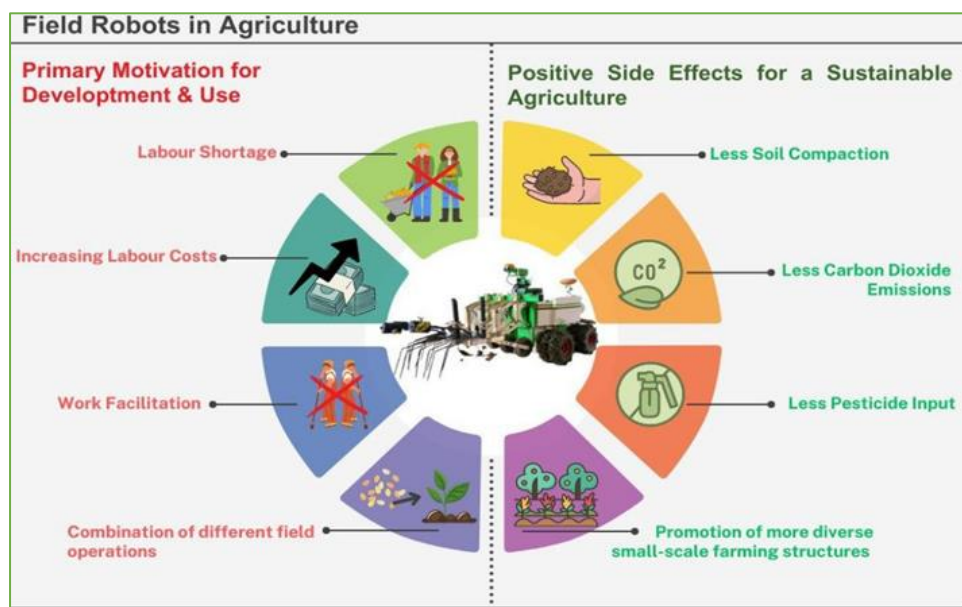


图 76: 田间机器人在农业领域开发和使用的主动机及其对可持续农业的积极影响

减少农药污染

精准农药施用的主要目标是降低成本和时间，同时减少资源使用。传感器、田间机器人和无人机等技术可以区分作物与杂草，实现精准施药。数字技术帮助农民实施德国的农药管理法规，并推广“数字昆虫陷阱”等工具。精准施药技术减少了农药使用，对生态环境有积极影响。

研究表明，编程模型可以评估农药对土壤生物的风险。绿色释放技术等创新减少了农药对环境的影响。数字技术在农药管理中的应用需要进一步推广和优化。

农作物多样性与轮作

德国农业以简单的轮作模式为主，主要种植谷物、玉米、土豆和甜菜等作物。这些作物对土壤肥力有负面影响，特别是玉米、土豆和甜菜。轮作规划需要考虑多种因素，数字技术可以帮助收集和分析相关数据。精准导航、传感器和无人机等技术有助于优化土壤管理策略。人工智能和硬件技术可以处理大量数据，为作物选择提供建议。数字技术的应用需要进一步推广，以提高农业生产的可持续性。通过数字技术实现作物多样性和轮作的优化是未来农业发展的关键。

自然保护与生物多样性

机器人除草技术可以增加土壤密度，减少传统农业机械对土壤的破坏。土壤压实会破坏孔隙结构，影响水和氧气的供应，进而影响土壤生物。长期休耕和单一作物轮作会导致土壤动物多样性下降。土壤生物在养分循环中起关键作用，对农业生态系统服务至关重要。基于人工智能的机器人技术可以检测和消除杂草，减少除草剂使用。田间机器人可以全天候工作，支持小规模生态友好型农业模式。数字技术在生物多样性保护中的应用需要进一步研究和推广。

适应气候变化与创新种植系统

数字技术无法阻止气候变化，但可以帮助农民更快地实施新的田间管理和种植系统。农林复合系统通过多样化作物和树种提高土壤碳储量和生物多样性。AgoraNatura 平台通过众筹支持自然保护项目，促进生物多样性保护。NatApp 等数字技术帮助农民应对气候变化的行政负担。Uckerbot 田间机器人支持生态甜菜种植，同时促进杂草多样性。数字技术的应用需要更多政策支持和资金投入。通过数字技术实现农业的气候适应是未来发展的关键。

农民与利益相关者之间的沟通与知识共享

农业知识与创新系统（Agricultural knowledge and innovation system, AKIS）为农民提供了新的学习机会。农民、农场和农业推广服务之间的沟通是推动创新的关键。德国农民普遍使用智能手机，认为数字技术可以简化农场工作流程。农民希望通过数字技术提高生产效率和可持续性。知识共享需要在地方、国家和欧盟层面同时进行。数字技术的应用需要更多农民参与和政策支持。通过数字技术促进农民与利益相关者之间的沟通是农业创新的重要途径。

障碍与风险

数字技术在生物多样性保护中的实际应用需要更多研究。数字化农业管理带来了新的挑战和风险，如反弹效应和能源效率问题。数字技术可能进一步推动农业集约化，而非生态转型。

法律障碍、数据限制和数据保护问题是数字技术应用的主要障碍。数据管理面临法律和隐私问题，农民对数据保护持怀疑态度。经济因素限制了数字技术的广泛应用，特别是对小农户而言。数字技术的应用需要更多透明度和政策支持，以确保其可持续性。

经济与成本问题

当前数字技术主要用于优化农业流程，特别是提高作物产量。数字技术的应用需要多方利益相关者的参与，包括农民、技术开发商和政策制定者。德国农民面临的主要障碍包括农产品价格低、可持续措施实施困难以及数字化成本高。数字技术的高成本限制了其在农业中的广泛应用，特别是对小农户而言。政策制定者需要提供更多资金支持，以推动农业的可持续数字化。数字技术的应用需要更多公众参与和社会接受度。通过政策和经济支持实现农业的可持续数字化是未来发展的关键。

进一步集约化与可持续性

智能农业机械可能进一步推动农业集约化，威胁生态保护区。大规模农场与数字技术的结合可能对生物多样性产生负面影响。算法的开发主要集中在提高产量，而非生态保护。德国政府已制定人工智能和大数据战略，但需要与农民和自然保护专家密切合作。如果生态保护未被纳入数字技术的早期开发，后期将难以实现。数字技术的应用需要在提高产量和保护生态之间找到平衡。通过政策和技术创新实现农业的可持续发展是未来发展的关键。

数字技术的局限性与成熟度

数据质量是数字技术应用的主要挑战，特别是在小规模测量中。传感器的校准主要针对常见作物，其他作物和杂草的多样性未被充分关注。ISO-XML 格式在数据传输方面存在局限性，新的 EFDI 格式正在开发中。人工智能技术在作物和杂草识别方面面临分类模型的挑战。无人机在物种保护中的应用可能对鸟类造成干扰，需要进一步研究。植物病害的复杂性对数字技术的图像识别能力提出了更高要求。数字技术的成熟度需要进一步提高，以应对农业中的多样化需求。

行政负担与数字化的矛盾

德国农民的行政负担日益增加，影响了可持续措施的实施。数字管理平台并未简化复杂的法规和申请流程。自然保护措施的补贴金额较低，难以激励农民参与。数字技术的应用需要更多政策支持和资金投入。通过简化行政流程和提高补贴金额，可以促进农业的可持续发展。数字技术在减少行政负担方面的潜力需要进一步挖掘。政策制定者需要提供更多支持，以减轻农民的行政负担。

天气依赖性与数字技术的局限性

农业完全依赖环境条件，数字技术可以帮助监测天气，但无法预测极端天气。气候模型的多样性导致预测结果不一致，难以精确评估人类活动对气候的影响。数字技术在天气监测中的应用需要进一步优化。通过数字技术提高农业的气候适应能力是未来发展的关键。数字技术的应用需要在天气依赖性和气候预测之间找到平衡。政策制定者需要提供更多支持，以应对气候变化对农业的影响。通过技术创新实现农业的气候适应是未来发展的关键。

网络安全问题

网络攻击和数据盗窃是数字技术应用的主要风险之一。农业数字技术的广泛应用使其成为网络攻击的潜在目标。信息基础设施的中断可能对农业生产造成严重影响。云存储解决方案可以帮助农民更好地保护数据安全。通过培训和多学科合作，可以减少网络攻击的风险。政策制定者需要提供更多支持，以应对农业中的网络安全问题。通过技术创新和政策支持实现农业的网络安全是未来发展的关键。

数字技术的权衡

数字技术的生产和使用需要大量能源和稀有资源，可能对环境造成负面影响。稀有金属的开采和加工可能违反人权或劳动权利，并对环境造成污染。数据中心的能源消耗和热量损失对全球变暖有负面影响。数字技术的广泛应用需要更多关注其环境和社会成本。通过技术创新和政策支持实现数字技术的可持续发展是未来发展的关键。数字技术的应用需要在技术进步和环境保护之间找到平衡。通过多方合作实现数字技术的可持续发展是未来发展的关键。

8. 关键建议

为实现德国农业数字化在可持续性和自然保护方面的推进，本研究提出以下核心建议：

a. 总体建议

政府应成为数字化与可持续农业实践的服务和咨询提供者，促进农民与管理者的顺畅沟通。通过财政支持推动农民采用数字技术实施可持续管理措施，加速未来 10 年的技术落地。避免对不可持续农业实践征税，以免挫伤农民积极性，需通过正向激励推动数字技术应用。专家对话表明，农民对当局存在畏惧心理，需通过经济支持增强其技术应用意愿。简化数字工具的资金申请流程，可提高农民使用技术的主动性和覆盖率。当前政策需从惩罚性转向支持性，以构建农民与政府间的信任关系。建议建立数字化补贴专项通道，直接关联技术应用与资金获取。未来十年需通过政策引导，将数字技术深度融入农业生态转型的核心战略。

b. 生物群落网络

区域内所有利益相关者需建立物理与数字连接的“生物群落网络”，整合自然保护资源。农民需开辟自然保护价值区域，市政部门则需激活未开发土地的生态潜力。建立跨区域知识共享平台，涵盖生态修复、生物多样性保护等核心议题。开发匿名咨询功能，使农民可直接联系专家或与其他面临相似问题的农户互动。现有公民科学平台（如 Map of Life）存在数据更新滞后、政治支持不足等问题。欧盟级平台 SMART AKIS 信息陈旧，许多标注“已上市”的技术实际已退出市场。语言障碍（德英混杂）和信息碎片化严重制约农民获取有效数字技术信息。亟需建立统一、多语言、实时更新的国家级农业数字技术数据库。

c. 技术兼容性与数据可靠性

提升不同厂商数字技术的兼容性，制定标准化接口以促进跨系统协作。技术设计需更注重用户友好性，降低农民的学习和使用门槛。厂商应明确技术适用范围（如地块规模、作物类型、气候条件等），但目前信息透明度不足。建议成立国家级“农业数据空间”，集中管理科学化处理的农业数据。当前农业数据分散于各州，需打破联邦主义壁垒，建立全国统一的数据门户。德国现有 230 家农业数字技术供应商，市场过度碎片化导致信息获取困难。数字行政程序仍需简化，现有自然保护补贴申请流程复杂挫伤农民积极性。数据可靠性需通过中央监管机构保障，研究者呼吁建立可信赖的数据共享机制。

d. 明确法律规范与数据安全

制定明确的数据主权法规是数字技术广泛应用的前提条件。无人机使用面临冗长的审批流程（如欧盟 2019/947 法规），增加农民的行政成本。外包无人机服务时，农民需承担额外管理成本，降低技术应用吸引力。田间机器人等自主技术仍处于欧盟机械指令（2006/42/EC）的法律灰色地带。需修订现行法律框架，明确自主农业设备责任归属与操作规范。数据安全立法应强化非个人数据的保护，解决农民对敏感数据泄露的担忧。建议设立农业数字技术专项法律咨询通道，降低合规风险。推动欧盟层面协调，建立适应农业特点的数字技术监管体系。

e. 教育与支持

当前数字技术研究多为实验室原型，距实际应用成熟度差距显著。避免分散开发无实用价值技术，应重点扶持具有可持续潜力的创新方向。政策需引导研发资源投向可提升生态效益的实践型数字技术。建立“技术-生态”关联数据库，例如明确哪些技术有助于保护农田步甲科生物。加强农民数字技能培训，特别关注中小型农场的技术应用能力建设。推动产学研合作，将农民实际需求纳入技术开发初期阶段。开发模块化数字工具包，允许农民根据自身需求灵活组合技术方案。在 CAP（共同农业政策）中增设数字技术应用专项奖励机制。

f. 降低成本

数字技术购置与使用成本需大幅降低，特别是面向中小型农场的解决方案。农场管理系统（FMIS）等软件价格高昂、操作复杂，限制其在生态保护中的应用。使用数字技术实施自然保护可能导致农民收入减少，需建立补偿机制。田间机器人共享模式可行性低，因除草作业时间窗口狭窄且设备效率有限。无人机搜救幼鹿服务单日成本约 5000 欧元，远超普通农场承受能力。建议政府资助独立测试中心，避免农民成为新技术的“试验品”。数字技术研发阶段需纳入生态影响评估，而非仅关注增产效果。通过 CAP 提供专项补贴，将数字技术应用与减排措施（如精准施药）直接挂钩。

g. 基础设施

亟需改善农村宽带网络和 GPS 信号覆盖，夯实数字技术应用基础。农业价值链全环节数字化，包括法律框架和资助计划的电子化转型。最大挑战在于构建技术解决方案与社会需求间的协同互操作性。建议德国联邦食品与农业部（BMEL）牵头协调数字化转型进程。创建标准化开放数据平台，整合 CAP 中的自然保护项目信息。建立数字化公共服务窗口，提升政策、行业与社会间的信息透明度。推动跨部门数据共享，特别是土壤轮作、产量等历史农业数据的开放获取。加强 5G 等新型基础设施在农业场景的优先部署，支持实时数据传输需求。

9. 总结

农业对环境的负面影响

德国农业对环境的负面影响显著，占全国温室气体排放的 8.35%，是甲烷和一氧化二氮排放的主要来源。水体中氮和硝酸盐浓度等有害物质超标，对生物多样性和生态状况造成严重破坏。农业及其周边区域（包括自然保护区）因集约化管理而受到负面影响，昆虫生物量在过去 30 年减少了 75%。农业依赖自然资源，既是环境问题的肇事者，也是其影响的受害者，涉及植物、土壤健康和气候变化等多方面。尽管已有 IPCC、SDGs 等转型概念，但实现这些目标的具体路径尚不明确。数字化和智能农业技术被视为实现可持续农业的关键工具，有望在保障产量的同时减少环境危害。德国农业的可持续转型需要整合所有可用资源，快速高效地实现目标。

数字技术在农业的应用

农业数字化并非新概念，自 20 世纪末以来，机器人、传感器和卫星数据等技术已推动精准农业的发展。精准农业最初关注经济效益，而智能农业则旨在通过数字技术减少环境负面影响。农业 4.0 趋势在过去 13 年中兴起，旨在通过数字化解决粮食安全和气候变化问题。德国市场上已有 201 种数字技术，分为复杂数据处理系统、软件技术和硬件技术三大类。复杂系统包括机器学习和人工智能，能够处理大量数据并优化农业流程。软件技术涵盖农场管理信息系统、

决策支持系统和数字平台，用于数据共享和协作。硬件技术包括传感器、田间机器人和无人机，用于收集环境数据并执行特定农业任务。

挑战与政策建议

农民在数字化实践中面临兼容性、数据主权、成本和培训等挑战，导致对技术的怀疑。调查显示，农民和行业参与者认为数字化技术有助于资源节约、区域管理和减排，但需明确框架支持。政策在制定框架条件、激励措施和推动可持续转型中起关键作用，应避免抑制创新的标准和法律。政策应促进标准化和互操作性，防止市场垄断，保障数据安全和主权。数字化技术既可支持可持续农业，也可能加剧不可持续的集约化，因此需谨慎引导。行业、政策制定者、农民和社会应共同设计可持续农业模式，而非仅依赖技术发展。在气候变化和生物多样性下降的背景下，政策应优先发展非商业导向的农业数字化模型。

本研究原本（英文）下载地址：

<https://www.econstor.eu/bitstream/10419/284380/1/1882289021.pdf>

10 Best-practice examples from other European countries

In this chapter, best practice examples of technologies that can be applied in practice in Germany are listed with a short description in Table 3 to Table 5.

Table 3. Best-practice examples of digital and smart farming technologies available and applied other European countries (EU and Austria).

Country	Technology	Short description
Europe-wide	FaST https://fastplatform.eu/	FaST digital service platform will make available capabilities for agriculture, environment and sustainability to EU farmers, Member State Paying Agencies, farm advisors and developers of digital solutions. The vision is for the FaST to become a world-leading platform for the generation and re-use of solutions for sustainable and competitive agriculture based on space data (Copernicus and Galileo) and other data public and private datasets. The modular platform will support EU agriculture and the Common Agricultural policy by also enabling the use of solutions based on machine learning applied to image recognition, as well as the use and reuse of IoT data, various public sector data, and user generated data.
	Agri-food data portal https://agridata.ec.europa.eu/extensions/iacs/iacs.html	The data portal hold by the European Commission provides a set of different data for and about agriculture in the EU. In the Agri-food data portal, data on national and European agriculture and common agricultural policy (CAP), are provided by the European Commission's agricultural and rural development department. The available data range from geodata, available in the Member States Geoportal. This portal delivers geodata of and for all regions of the member states, including some IACS data. Further portals provide farm economic data (FADN public data base); data about the agri-food market, CAP indicators, EU financing, country fact sheets as well as data about food supply and security.
	DigitAF https://digitaf.eu/	Founded by the EU, a consortium of 26 European and international partners committed to provide digital tools to boost Agroforestry in Europe. The key actions are 1) to collect data and evidences to support policy and decision makers for the implementation of agroforestry systems: 2) to improve communication and boost networking to reach different targets; 3) to implement a tailored multi-actor approach directly engaging with stakeholders whose decisions impact the spread of agroforestry practices.
Austria	Aws KI-Marktplatz www.ki-marktplatz.at	In 2021, a marketplace for AI was launched to provide an overview of the supplier landscape and their services in the field of artificial intelligence. Its goal is to establish contacts between AI suppliers and potential customers, and to introduce Austrian companies to AI applications. This enables market participants to find suitable partners more quickly and thus contributes to increased market dynamics (with more growth and employment).
	CORDULUS Cordulus Farm https://www.cordulus.com/de/	Technology company that delivers hyper-local weather data and AI solutions to their customers, that helps them in making proactive decisions and managing risks. With Cordulus Farm, Cordulus delivers weather station solutions to farmers. The technology enables localised forecasts to be made for fields, giving an advantage in planning agricultural activities, and making farm management easier. The actionable weather data can increase agricultural efficiency, reduce costs, and save time.
	Telesense https://www.telesense.ag/	TeleSense develops, produces, and sells wireless sensors which measure temperature and relative humidity. The products are used to monitor and ensure the security of biological products. TeleSense has a simple interface which makes it easy for users to monitor their stores. It can easily be accessed from PC, tablet or mobile.

Table 4. Best-practice examples of digital and smart farming technologies available and applied other European countries (Finland, Latvia, Netherlands, Norway).

Country	Technology	Short description
Finland	Mtech Digital Solutions Oy https://www.mtech.fi/en/	Mtech is a Finnish pioneer in smart food supply chains. They provide information systems and process integrations, data storage solutions, analysing and reporting solutions, mobile solutions, and cloud services. The company is also a trusted digital partner of advisory organisations, breeding associations and public authorities in the agricultural sector.
	EFI https://efi.int/projects/digitaf-digital-tools-help-agroforestry-meet-climate-biodiversity-and-farming	The European Forest Institute is a Finnish research institution with the aim of enhancing international forest research and providing decision makers with unbiased forest-related information at a pan-European level. EFI is one of the main stakeholders in the DigitAF project (<i>see DigitAF above</i>).
Latvia	Rural Support Service https://karte.lad.gov.lv/	Free of charge rural support service, which provides publicly accessible information about agricultural fields. The data receives daily updates.
Netherlands	VanderSat https://docs.vandersat.com/VanderSat_Data_Products.html	VanderSat is a leading provider of global satellite-observed data, products, and services over land with a special emphasis on water and crops. VanderSat offers a unique and patented technology that makes observations possible without any cloud and darkness interference. VanderSat gives its customers essential insights into soil and crop conditions by applying mathematical expertise to raw data from a constellation of satellites. For farmers, delivers valuable soil moisture, biomass proxy and inundation data.
	AgroExact weather stations https://www.agroexact.com/ 1) Soil Exact 2) Crop Exact	1) The soil moisture sensors of AgroExact provide watering instructions by measuring soil moisture at root depth. The most up to date irrigation advice is included in AgroExact app. 2) Sensor to monitor the harvest: monitoring of precipitation, temperature, soil temperature, air moisture, field capacity
Norway	DigiFarm https://digifarm.io/ 1) Delineated Field Boundaries 2) Deep Resolution Imagery 3) Sustainability Index 4) S2 Time-Series 5) Productivity Zones 6) Weed Detection (soon) 7) Automatic Yield Mapping (soon)	ag-tech startup developing technology for automatically detecting the highest accuracy field boundaries and seed acres using deep neural network models and super resolved EO data 1) Automatic detection of field boundaries and seeded acres 2) Sentinel-2 images up to 1-meter-deep resolution 3) Multi-year analysis of vegetation indices, such as EVI/ NDVI 4) Long-term and in-season cloud filtered vegetation indices on the same chart. 5) Historical biomass accumulation in low, medium, and high zones 6) Based on digital image processing and computer vision. 7) A simple system to generate yield maps in a reliable, low-cost manner
	Kilter AX-1 https://businessnorway.com/solutions/kilter-robotic-weeder-radically-reduces-herbicide-use-and-increases-yields	Kilter's autonomous weeding robot for precision farming, the AX-1, aims herbicide droplets directly at weeds without hitting the crop or soil. A machine vision system maps its way by identifying the shape and position of every weed and crop. Simultaneously the patented nozzle matrix aims individual droplets of herbicide at the weed leaves without touching the crop or soil. The nozzle even hits weeds entangled in the crop, enabling the use of novel weeding agents for herbicide-sensitive vegetable crops.
	Thorvald https://sagarobotics.com/thorvald-platform/	Thorvald has been designed to work across all farming environments and terrains. Its modular construction means there are almost limitless possibilities for adaption, tools, and applications. While Thorvald performs autonomous farming tasks, you and your team can focus on managing the farm as a whole. Thorvald is a number of different robots rolled into one, all built using the same basic modules, and rebuilt using only basic hand tools. The modules are designed to enable high quality robots that can quickly be customised for a given application in a given environment, such as a greenhouse, tunnel, open field and vineyard.

Table 5. Best-practice examples of digital and smart farming technologies available and applied other European countries (Switzerland).

Country	Technology	Short description
Switzerland	xFarm https://xfarm.ag/iot-sensors/?lang=en 1) xSense devices 2) Digital platform <i>Also: for Italy and Spain</i>	1) Smartly connected sensors to each other and to the xFarm platform. xSense stations are equipped with a sim card that allows to send data via GSM to the platform, while all xNode modules use the LoRa wireless system, which allows very low battery consumption, up to ten kilometers radius (depending on environmental conditions) and connect up to 100 devices on the same network. Internet of Things (IoT) is the characteristic that distinguishes xFarm sensors and means that the devices are interconnected and that they can communicate via internet directly with the account. 2) xFarm is a singular platform, accessible from any device and equipped with dozens of different modules. A simple and intuitive interface allows to control fields and activities: - via a map all land of a farm can be visualized from satellite and land registry –all details of the fields can be read - simple activity: registration and rapid programming of field activities – notes: registration of memo on an activity or in a specific location Data can be used to improve efficiency. Collected data via sensors and interfaces to develop decision-making tools, maps and forecasting models are capable of giving personalized advice for plots. Irrigation advice can be received based on sensors, watering program and activate the systems. For fertilization prescription maps for variable rate fertilizer application can be obtained that evaluate the diversity of plots. For plant protection the app delivers information on how to use phytosanitary products through the databases and when to take action through the forecasting models based on sensors measurements. Telemetry to control the performance of vehicles, send prescription maps and allocate fuel costs.
	Barto https://www.barto.ch/de/fuer-bauern-und-baeuerinnen/das-ist-smart-farming	Barto is a web-based platform for managing the entire farm and fulfilling documentation obligations. Web-based means the platform is accessible from anywhere with internet access. Log in works with familiar Agate access data. This eliminates the need for a tedious registration process. In addition, other modules can be added to the basic function. Thereto account for example: storage module; crop rotation and crop planning module or a meadow and outdoor journal.
	1) Global FieldID 2) SoilHive https://www.varda.ag	To tackle the challenge of data fragmentation in the agricultural industry and address the lack of standards of data produced on farms every day. After ingesting and validating field boundaries, Global FieldID™ assigns a unique alphanumeric code to each field, enabling field identification of agricultural land plots, globally. Global FieldID is like a ‘QR code for fields’ that allows the identification of agricultural land plots in a standard way across digital farming tools, agricultural service providers and the food value chain, making the flow of information easier and cheaper. 2) SoilHive is a web-based platform that consolidates and harmonizes soil data from public and private data sources based on voluntary contributions. The platform gives access to fragmented and invisible soil data for public and commercial purposes, acting as a catalyser for global collaboration for soil health.

Appendix Table 8. Overview and short description of AI-based technologies, commercially available in Germany (A–W)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application area	Source link
AgriGaia	Agrotech Valley Forum e. V.	Open AI ecosystem for the agri-food industry based on GAIA-X, the European sovereign data infrastructure.	Free of charge	Crop cultivation/ livestock/nature conservation	https://bit.ly/3twpYTi
agriGPT	LV digital GmbH	Virtual assistant for agriculture.	Free of charge	Crop cultivation	https://bit.ly/45CamuY
ANA App	Spacenus GmbH	Agricultural nutrient assistant for fertiliser recommendations based on satellite imagery	Subject to charge	Crop cultivation	https://bit.ly/45tpGtF
API Field Boundary	Spacenus GmbH	Field Boundaries by request: the system provides a polygon of the field geometry. Based on field geometry classification of zones is possible.	Subject to charge	Crop cultivation	https://bit.ly/3SeVIH1
API Field Map	Spacenus GmbH	Platform for illumination of different field maps: nitrogen shortage, disease risk, soil productivity, nitrogen uptake, vegetation index and dry matter maps.	Subject to charge	Crop cultivation	https://bit.ly/3FfSFXe
heliopas.ai	heliopas.ai GmbH	Platform for a wide variety of analytics with highly accurate data daily based on parameters such as soil homogeneity, soil moisture, crop type, land usage, floor bearing capacity and plant health.	Subject to charge	Crop cultivation	https://bit.ly/3LYmdMB
John Deere Command Cab	John Deere Walldorf GmbH & Co. KG	Operating concept containing joystick control, touchscreen screen and networking of all machine components. Through the integration of real-time weather data, individual presets and order management, the cabin becomes a command centre for the farm.	Subject to charge	Crop cultivation/ administration	https://bit.ly/45wz9Ae
KPI map	Spacenus GmbH	Automated process of estimation of the carbon sequestration potentials. The user provides field boundaries and crop history data and the app gives recommendation for sampling. After sampling the data is being utilised and given back to the user.	Subject to charge	Crop cultivation	https://bit.ly/3rRpGGc
Mantis (Augmenta field analyzer)	Augmenta (Raven, CNH industrial brand)	AI-based visual analyser – automatically calibrates rates according to the in-field variability according to the initial input. Pre-calibration possible through agronomical algorithms.	Subject to charge	Crop cultivation	https://bit.ly/45o42Ha
NutriLabApp	MMM Tech Support©	App for interpreting and archiving measured values from the press juice analysis of fresh plant organs. The app can be used with a computer, tablet, or smartphone.	Subject to charge	Crop cultivation	https://bit.ly/48UfoWf
See & Spray (John Deere)	John Deere Walldorf GmbH & Co. KG	With See & Spray technology, high-resolution cameras capture 20 images per second. Based on the images and artificial intelligence, the system recognises the difference between cultivated plants and weeds so that individual plants can be specifically treated.	Subject to charge	Crop cultivation	https://bit.ly/3RVrFDO
Waterfox	heliopas.ai GmbH	AI-based sensorless and yield-optimised irrigation scheduling tool	Subject to charge	Crop cultivation	https://bit.ly/46JFA47

Appendix Table 9. Overview and short description of farm management information systems (FMIS), commercially available in Germany (3–A–V)

Digital Technology name/brand	Manufacturer/ <u>D</u> istributor	Short Summary	Availability	Application area	Source link
365FarmNet Platform	365FarmNet GmbH	Agricultural software program that administers data coming from the crops or livestock. The software allows automation of data, cross-compliance, nutrient reporting, and document administrative tasks.	Free of charge	Crop cultivation/administration	https://bit.ly/3NpbR8J
AGRAVIS NetFarming	AGRAVIS Raiffeisen AG	Big data-based software for agriculture. The software works with data from various networked web tools in cooperation with geo-konzept GmbH.	Subject to charge	Crop cultivation/administration	https://bit.ly/3r1KBFr
Amazone 4.0	Amazonen-Werke H. Dreyer SE & Co. KG	Optimises operational processes and helps farmers to work more precisely and efficiently, conserve resources with the help of software, electronics, service, and networking.	Subject to charge	Crop cultivation/administration	https://bit.ly/3Js6eFt
DELOS	OVIS IT GmbH	Arable land use index in the browser and as an app for your mobile phone for federal state-specific fertiliser requirement planning and material flow balances in accordance with the latest legal requirements.	Subject to charge	Crop cultivation/administration	https://bit.ly/3rAtBHm
Greenspin mofato (Croptify)	Green spin GmbH	A decision-making support that provides global, satellite-based monitoring of growing conditions on agricultural land – updated daily.	Subject to charge	Crop cultivation/administration	https://bit.ly/3rO0KiH
MyFarm24 HELM Software (shareMyFarm)	HELM-Software	shareMyFarm manages the complete documentation on a farm and allows communication with partners.	Subject to charge	Crop cultivation/administration	https://bit.ly/48JU0mF
NEXT Farming Pro	FarmFacts GmbH	The software networks data islands and extracts the maximum amount of information from the daily flood of data in a structured way.	Subject to charge	Crop cultivation/administration	https://bit.ly/3tqrBBX
NEXT Farming Live	FarmFacts GmbH	Intelligent networking of mixed fleets and cross-manufacturer integration of important machine data.	Subject to charge	Crop cultivation/administration	https://bit.ly/45pqy2j
ProFlura	ASSW GmbH & Co KG	Documentation software for market fruit, fodder, vegetable, fruit, wine, hops and biogas farms for all federal states and neighbouring EU countries.	Subject to charge	Crop cultivation/administration	https://bit.ly/45kP2tv
sigAgroasesor	ITAP, NEIKER, IFAPA, AEMET, INTIA, S.A.	It integrates public information, databases and cartography using GIS-WEB services. The platform enables the operation of several Decision Support Tools with geo-localised information of each agricultural plot, and accessing data from remote sensors or different databases.	Subject to charge	Crop cultivation/administration	https://bit.ly/3rKs4yl
TAP Topcon Agriculture Platform	Topcon Deutschland Positioning GmbH	Software with three modules – Fields, Fleet and Pro, for documentation management, machinery tracking, data networking and decision-making.	Subject to charge	Crop cultivation/administration	https://bit.ly/3LPWB4r
VarioDoc Pro/Fendt Task Doc	Fendt/ AGCO GmbH	Software for management documentation. Processing of files in ISO-XML format as well as application maps in Shape format possible.	Subject to charge	Crop cultivation/administration	https://bit.ly/48KcoM9

Appendix Table 10. Overview and short description of decision support systems (DSS), commercially available in Germany (A–X)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application area	Source link
agriDOC	Agricon GmbH	Fully automatic documentation for field management and provides access to advisory services. Various modules available.	Subject to charge	Crop cultivation/administration	https://bit.ly/3NGKKqQ
AGROCOM NET	CLAAS KGaA	Digital farmland register.	Subject to charge	Crop cultivation/administration	https://bit.ly/44cYpLW
CLAAS connect	CLAAS KGaA	Digital field diary with telemetry data of agricultural machinery based on a remote service contract.	Subject to charge	Crop cultivation/administration	https://bit.ly/44bnxCF
CLAAS TELEMATICS	CLAAS KGaA	Continuous digital documentation and retrieving of work data, tracks, yield data, combine harvesters, forage harvesters, tractors.	Subject to charge	Crop cultivation/administration	https://bit.ly/3JqLrCl
Climate FieldView™	The Climate Corporation International SA	Digital platform for farmland management with integration of digital maps.	Subject to charge	Crop cultivation/administration	https://bit.ly/3PIK5wb
CropSAT	Dataväxt AB	Visualisation of crop biomass variation for decision support of fertiliser and pesticide applications.	Free of charge	Crop cultivation	https://bit.ly/3Xi1Dv4
EcoPay	UFZ, Freie Universität Berlin, BTU	Ecological-economic modelling to compare organic and conventional farming on endangered grassland bird and butterfly species.	Subject to charge	Nature conservation	https://bit.ly/3CE3X6n
EOS Data Analytics	EOS Data Analytics, Inc.	Satellite-based crop monitoring solutions for monitoring, scouting, management, weather, and zoning.	Subject to charge	Crop cultivation/administration	https://bit.ly/3NHno4q
FAIRshare - Digital Tools for Farm Advisors	Gato de Bigode/EU	Digital assessment tool helping farm advisors to compare different digital tools, address their needs and evaluate it.	Subject to charge	Crop cultivation	https://bit.ly/43PNOXp
Isaria Connect	Fritzmeier Umwelttechnik GmbH & Co. KG	Software solution for data and task management.	Subject to charge	Crop cultivation/administration	https://bit.ly/3XglOtz
Magic Scout	Bayer AG	Digital tool for plant pests' and disease recognition, weather analysis and field diary.	Subject to charge	Crop cultivation	https://bit.ly/3NiWLRR
MyDataPlant	Kleffmann Digital RS GmbH	Software for site-adapted decision making based on satellite imagery.	Subject to charge	Crop cultivation	https://bit.ly/3thXZ9F
MyEasyFarm	MyEasyFarm	Software solution to support the management and optimisation of arable farms.	Subject to charge	Crop cultivation	https://bit.ly/3Q7LzKu
NEXT Farming Office App	FarmFacts GmbH	App for work documentation, information collection and data analysis on site	Subject to charge	Crop cultivation/administration	https://bit.ly/3ZM5NwF
SatAgro	SatAgro Sp. zo.o.	Digital, personable maps compatible with a wide range of agricultural machinery with Cloud Computing.	Subject to charge	Crop cultivation	https://bit.ly/3CD9pq6
Talking FieldsMaps	Vista GmbH – Remote Sensing in Geosciences	Digital map based on geostatistical analysis of satellite data for making site-specific crop cultivation decisions.	Subject to charge	Crop cultivation	https://bit.ly/3RS2jqq
Xarvio® FIELD MANAGER	BASF Digital Farming GmbH	Software solution for optimising field and field zone specific crop production based on more than 30 crop optimisation models.	Subject to charge	Crop cultivation	https://bit.ly/3PQYUFD
Xarvio® HEALTHY FIELDS	BASF Digital Farming GmbH	Software optimises field and season-specific application timing, product, and dosage for crop protection. Can be used with own machines or with a contractor.	Subject to charge	Crop cultivation	https://bit.ly/46nYIKI
Xarvio® SCOUTING	BASF Digital Farming GmbH	Application for instant pheromone trap analysis function to support growers of grapes and fruit in Europe.	Subject to charge	Crop cultivation	https://bit.ly/3LQPjOz

Appendix Table 11. Overview and short description of digital technologies for guidance and steering (DTGS), commercially available in Germany (A–E)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
AES-35	geo-konzept GmbH	For vehicles without a steering system pre-installation. It combines the performance of a hydraulic system with the convenience of an electric solution. Accurate electric steering with RTK accuracy of up to 2.5 cm - even in reverse.	Subject to charge	Crop cultivation	https://bit.ly/3OXumU4
AFS AccuGuide™ komplett von Case IH	<u>CNH Industrial Österreich GmbH</u>	Automatic track guidance in the field with an accuracy of up to 2 cm, with up to 6 active screens with field maps, track guidance system settings and tractor and implement functions.	Subject to charge	Crop cultivation	https://bit.ly/3OVqlPM
AFS AccuTurn Pro and HMC II	CNH Industrial America LLC	Next-generation auto guidance technology for automated headland-turning, using the same software logic found on Autonomous Concept Vehicles. The system reduces operator fatigue and increases productivity by automatic repeatable turns.	Subject to charge	Crop cultivation	https://bit.ly/3MPqVMt
AFS Connect™ - Advanced Farming Systems	<u>CNH Industrial Österreich GmbH</u>	The system enables real-time remote monitoring and management of operational and fleet data activities of all tractors in fields.	Subject to charge	Crop cultivation	https://bit.ly/3OVsFX0
(agri) EASE Tool	European Union Agency for the Space Program	Provide farmers with cost-benefit analyses on the use of EGNOS for machinery guidance in some of their typical agricultural labours: sowing, spreading, spraying, and harvesting.	Free of charge	Crop cultivation/ administration	https://bit.ly/3trYcqR
Autopilot™	CNH Industrial Österreich GmbH	A steering system that can be retrofitted to machines and models from many manufacturers. With the help of this retrofit, efficient agricultural work is possible, because a driver can work more precisely and over longer steering periods.	Subject to charge	Crop cultivation	https://bit.ly/3ITPkiP
CEMOS Advisor von CLAAS	CLAAS KGaA mbH	App as an optimisation aid on the smartphone when driving combine harvesters. The app enables error corrections and improves settings for less crop loss.	Free of charge	Crop cultivation	https://bit.ly/3Cg5csi
CLOUD farmunited	ETO DYNAMIC Digital GmbH und farmunited GmbH	Simple, geodata-based documentation of operating machines in the field. Device management, capture and management of programmes, jobs, and machine data. Access via mobile devices with web browser.	Subject to charge	Crop cultivation	https://bit.ly/3qx9QiI
CoGIS	geo-konzept GmbH	CoGIS offers a range of surveying, soil sampling and remote sensing functions for various service providers. It consists of the modules Basic, Mapping, Advanced Mapping and UAV. In the mapping area, the user can use simple GIS functions, such as the recording of points and areas, as well as more complex tasks, such as georeferenced soil sampling with automatic barcode generation.	Subject to charge	Crop cultivation	https://bit.ly/3CeCRSY
Easy on board von CLAAS	CLAAS KGaA mbH	The app provides for documentation with any AEF-certified field cards. The exchange of job data is done via email per ISO-XML file. The machine can be controlled via iPad using ISOBUS.	Subject to charge	Crop cultivation	https://bit.ly/3OXR4LU
EZ-Pilot™	CNH Industrial Österreich GmbH	The steering system turns the steering wheel using an integrated electric motor to keep your hands free. It still allows unrestricted manual steering when the power steering is not engaged, and manual intervention is possible at any time.	Subject to charge	Crop cultivation	https://bit.ly/3oShLH1

Appendix Table 12. Overview and short description of digital technologies for guidance and steering (DTGS), commercially available in Germany (F–T)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
Fahrspurplanung geoTRAX	geo-konzept GmbH	Practically developed software module for planning lanes for any impact shapes. Free choice of headland and working direction, planning for partial areas of the field is also possible.	Subject to charge	Crop cultivation	https://bit.ly/3WR02w8
farmpilot-App	Arvato Systems GmbH	Once the data has been transferred to the app, position data and status information is sent while the work is being carried out. This gives an overview of fleet and the progress of job processing in real time.	Free of charge	Crop cultivation/ administration	https://bit.ly/3MUUsnS
Field Navigator app	Farmis Inc.	App for accurate, parallel driving in Precision Farming. Measures the size of the farm, arable land, or grassland, without the necessary additional and expensive equipment.	Free of charge	Crop cultivation	https://bit.ly/43w2Kde
FieldBee app	eFarmer B.V., Incorporated	Tractor navigation system or automatic steering system based on RTK with high accuracy of 2.5 cm and easy installation.	Free of charge	Crop cultivation	https://bit.ly/43HjwWn
IntelliSteer™	New Holland Agriculture (a brand of CNH Industrial©)	A fully integrated automatic steering system developed by New Holland. One monitor can be used for machine functions, automatic steering, mapping and implement control. Grade compensation is achieved by sensing the machine's roll, pitch and yaw movements and correcting them to avoid misses and overlaps on uneven ground.	Subject to charge	Crop cultivation	https://bit.ly/45VnHzC
Reichhardt PSR SLIDE – Shifting frame	geo-konzept GmbH	Active implement steering for special crops, row crops, vegetable crops. Track guidance can be provided by a high-precision RTK steering system or optionally by ultrasonic sensors from Reichhardt. The shifting frame can be used universally and independently of vehicle and implement.	Subject to charge	Crop cultivation	https://bit.ly/3oSzeza
RTK-Netzwerk AgCelNet	geo-konzept GmbH	The RTK network AgCelNet enables the reception of correction data throughout Germany. The central computer can provide correction data in different formats - for different receiver makes - and for GPS and GLONASS simultaneously. The correction data from RTK networks are accessible via the internet.	Subject to charge	Crop cultivation	https://bit.ly/3MZJc9Z
SMARTPILOT farmunited	farmunited GmbH ETO DYNAMIC Digital GmbH	Modular ultrasonic steering system for tractors, work platforms and harvesters. Precise navigation in plantation rows and tramlines. Precise navigation in plantation rows and tramlines. Orientation on parallel or single rows.	Subject to charge	Crop cultivation	https://bit.ly/3WXHI4p
Sprayer calibrator	Farmis Inc.	An GPS-based app that helps farmers choose and adjust the spray nozzle and keep track of the real-time flow rate of pesticides.	Free of charge	Crop cultivation	https://bit.ly/3qvFz44
TopNET Global	TOPCON Corporation	Satellite-based correction service with 4-10 cm accuracy and RTK service.	Subject to charge	Crop cultivation	https://bit.ly/3WZGd66
Trimble Center Point RX, Trimble RangePoint ® RTX	Trimble Inc.	The system provides high-accuracy GPS survey correction up to 2 cm via satellite or cellular delivery worldwide.	Subject to charge	Crop cultivation/ grassland	https://bit.ly/3NizyAp
TrueGuide	Trimble Inc.	A passive device steering system that monitors and corrects the position of the equipment by acting on the steering of the tractor.	Subject to charge	Crop cultivation	https://bit.ly/3J2QwR8

Appendix Table 13. Overview and short description of digital information platforms (DIP), commercially available in Germany (A–S)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
Agricultural Industry Electronics Foundation (AEF)	Agricultural Industry Electronics Foundation e.V.	Platform to establish and maintain transparency regarding the functionalities supported by specific products and their compatibility with others.	Subject to charge	Crop cultivation/livestock/nature conservation	https://bit.ly/3twHC9o
Einfache Feldgefügeansprache für den Praktiker (FGA)	Landwirtschaftsverlag GmbH	This guide to a simple field structure analysis is intended to help you to draw conclusions from the current state of the structure for gentle soil cultivation and driving.	Free of charge	Crop cultivation	https://apple.co/46vDNjs
Eip-agri Agriculture&Innovation	European Commission	The EIP-AGRI brings together innovation actors (farmers, advisers, researchers, businesses, NGOs, and others) in agriculture and forestry, at EU level. Together they form an EU-wide EIP network. On the digital platform knowledge transfer within the EU is possible.	Free of charge	Crop cultivation/livestock/Nature conservation	https://bit.ly/48TQeqQ https://bit.ly/3QhioEP
Farm21 Plattform	Farm21	Platform with multiple data sources from sensors (FS21), satellite images, public weather data. Exchange with other users possible.	Subject to charge	Crop cultivation/livestock/Nature conservation	https://bit.ly/3ZVvKda
GODAN (Global Open Data for Agriculture and Nutrition)	GODAN	Platform for agricultural and nutritional data to be available, accessible, usable, and unrestricted.	Free of charge	Crop cultivation/livestock/Nature conservation	https://bit.ly/40cqLFn
NatApp	ZALF e.V. / flynet	A software-based tool that enables the legally compliant, ordinance-compliant establishment, documentation, and control of environmental and climate actions.	Free of charge	Nature Conservation	https://bit.ly/48U39Jd
SAI Platform - Spotlight	SAI Platform	Supporting farmers with an online platform that helps align their work with local, regional, national, and international sustainability goals. The platform enables members to connect to other members while supporting their value and supply chains in a sustainable way.	Subject to charge	Crop cultivation/livestock/nature conservation	https://bit.ly/3LZE8k
Smart Farming Platform (Smart AKIS)	European Union	A free digital information platform providing several tools for disseminating and making easier the use of Smart Farming technologies. The platform is open to farmers, advisory services, agriculture consultants, and farming equipment providers, setting up an open community where these groups can interact.	Free of charge	Crop cultivation/livestock/nature conservation	https://bit.ly/45zOFeG

Appendix Table 14. Overview and short description of citizen science applications and platforms, commercially available in Germany (A–F)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
3000 Pflanzen bestimmen	Coogni GmbH	Database for the identification of more than 3100 plants, including trees, shrubs, perennials, annuals, biennials, ferns.	Subject to charge	Nature conservation	https://bit.ly/3Qe9Kak
Agoranatura	ZALF e.V./Universität Greifswald/Deutsche Umwelthilfe/DVL	The first online marketplace for certified nature conservation projects. It enables people who manage land and want to implement a nature conservation project to finance it through crowdfunding or partnerships with companies. Private investors and companies can specifically promote biodiversity and nature services through the purchase of nature conservation certificates.	Free of charge	Nature conservation	https://bit.ly/48Pflv1
ArtenFinder	Ministry for Climate Protection, Environment, Energy and Mobility Rhineland	The data transmitted on the portal will initially be kept available on the internet in a protected form exclusively for the user. The release of reports for quality assurance by the Species Data Coordination Unit requires your explicit consent. External experts then check the plausibility of the data before they are transferred to the official databases.	Free of charge	Nature conservation	https://bit.ly/3ZT5bWa
Bäume und Sträucher bestimmen	Palatinate/ Nature and Environment Foundation Rhineland Palatinate"	More than 330 trees and shrubs of the world recognise and name: native and immigrant trees and shrubs as well as garden trees.	Subject to charge	Nature conservation	https://bit.ly/3rZvs8u
Baumführer 2 PRO and Lite	Coogni GmbH	With the Tree Guide 2 PRO you get a practical identification and reference work of the most common tree species in Europe and North America.	Subject to charge	Nature conservation	https://apple.co/3ZXDxYc
BirdNET: Vogelstimmen einfach erkennen	NATURE MOBILE G.m.b.H.	BirdNET is an artificial neural network that has been trained to recognize the 500 most common bird species from North America and Germany. With this app you can analyse pictures of bird voices with your smartphone from BirdNET.	Free of charge	Nature conservation	https://bit.ly/3LZrtQn
Deutschlandflora App	Federal Ministry of Education and Research (BMBF)/ TU Chemnitz	The app makes it possible to enter plant observations directly in the field with GPS-accurate finding points. The observations can be supplemented with photos taken on site. The data are fed into the Deutschlandflora portal and made publicly available in summarised forms as distribution data by BfN on the website www.floraweb.de	Free of charge	Nature conservation	https://bit.ly/3QheEn2
Eh-da-Flächen	pocket.science	Initiators and responsible persons of an Eh-da project are citizens of a municipality, farmers, beekeepers, gardeners, Nature conservationists, everyone who has an interest in the ecological enhancement of the landscape. The experts of the Eh-da initiative support committed project initiators with corresponding digital maps and geodata material.	Subject to charge	Nature conservation	https://bit.ly/45qKnGt
Feldbotanik	Haupt Verlag AG	The field botanical app and the associated book <i>Fundamentals of field botanicals</i> are intended to be useful tools for anyone who wants to build up their botanical knowledge and train their knowledge of species.	Subject to charge	Nature conservation	https://apple.co/45t6Oeo

Appendix Table 15. Overview and short description of citizen science applications and platforms, commercially available in Germany (F–M)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
Flora Capture: digitale Pflanzensammlung	Technische Universität Ilmenau/ Max-Planck-Institiut für Biogeochemie	Plant observations are digitally uploaded and identified by botanists. Photographs of flowering wild plants from specified angles are used to train the image recognition algorithms that are used in the app.	Free of charge	Nature conservation	https://bit.ly/3S5qSQG
Flora Incognita: automatische Pflanzenbestimmung		Identification app for 4,851 wild plant species found in Germany. With automatic image recognition and by answering a few questions, the user is guided to the plant species they are looking for. The core of the app is an intelligent image recognition technique for identifying plants using smartphones and tablets.	Free of charge	Nature conservation	https://bit.ly/3FcWA7f
Frösche, Kröten, Unke bestimmen	Coogni GmbH	Frogs, toads, salamanders, newts determine in Germany, Austria, and Switzerland. An animal guide from Naturetouch.	Subject to charge	Nature conservation	https://bit.ly/3ZW0vNq
Früchte sammeln & bestimmen 2 PRO and Lite	NATURE MOBILE GmbH	Reference work for fruits and berries of the most common species of wild plants and crops.	Subject to charge	Nature conservation	https://bit.ly/3RYwOLk
Gartenvögel	Franckh-Kosmos Verlags-GmbH & Co. KG	Portray of the 37 most popular native garden birds. Own observations can be created in a list directly in the app.	Subject to charge	Nature conservation	https://apple.co/3rL9ne2
Heuschrecken bestimmen	Coogni GmbH	An animal guide from Naturetouch. Recognition and determination of all the important locusts of Germany.	Subject to charge	Nature conservation	https://bit.ly/3S28WXu
iFlora	Dr. Oliver Tackenberg	iFlora-Germany contains more than 2500 illustrations. Information on taxonomy, systematics, ecology, and distribution in Germany is also integrated into the app.	Free of charge	Nature conservation	https://bit.ly/3LYoUhp
Igel, Hase, Fuchs bestimmen	Coogni GmbH	Naturetouch determination of 74 mammals in Central Europe.	Subject to charge	Nature conservation	https://bit.ly/48TTnXG
iNaturalist – Mit anderen Usern Insekten bestimmen	California Academy of Sciences/ National Geographic	Naturalist is one of the most popular nature apps in the world for identifying the plants and animals. A community of over 800,000 scientists and naturalists with reporting and sharing own observations, research-quality data to scientists is being provided.	Free of charge	Nature conservation	https://bit.ly/3LYICti
Map of Life (MOL)	NASA, National Science Foundation (NSF), MacArthur Foundation	It is not only a reference work, but also a tool for "citizen science": you can use it to directly document animal observations and thus supplement and expand the Map of Life.	Free of charge	Nature conservation	https://bit.ly/3rVbonV
Mollusken Deutschlands - Datenportal	Deutsche Malakozoologischen Gesellschaft, BfN, Rote-Liste-Zentrum (RLZ)	Recording of snails and mussels for nature Nature conservation/ red lists The database offers an overview of current projects and scientific data providers as well as expert support.	Free of charge	Nature conservation	https://bit.ly/3QhyeiJ
Moose Deutschlands - Datenportal	BfN, DLR, RLZ, BLAM - Bryologisch-Lichenologische Arbeitsgemeinschaft für Mitteleuropa e.V.	Recording of moose for nature Nature conservation/ red lists The database offers an overview of current projects and scientific data providers as well as expert support.	Free of charge	Nature conservation	https://bit.ly/45zQdW2

Appendix Table 16. Overview and short description of citizen science applications and platforms, commercially available in Germany (F–M)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
NABU - Zeit der Schmetterlinge	NABU e.V.	Used to identify the most common butterflies in North Rhine Westphalia to report observations.	Free of charge	Nature conservation	https://bit.ly/3Q0jBiN
NABU Insektensommer	NABU e.V.	With the free app the user can identify, map and report the most common domestic insects.	Free of charge	Nature conservation	https://bit.ly/3PT9U5D
NABU Vogelwelt	NABU e.V.	Identification and reporting of 308 bird species through the app.	Free of charge	Nature conservation	https://bit.ly/3ZTJViz
Naturblick	Museum für Naturkunde Berlin	The user takes photos of plants and determines them with the automatic image recognition. The observations are recorded with location.	Free of charge	Nature conservation	https://bit.ly/3PYeu2p
Naturgucker.de-meldeapp	Naturgucker	Reporting app for observations, information can be recorded in the terrain and uploaded with images to the observations.	Free of charge	Nature conservation	https://bit.ly/45rWH9H
Neuropteren Deutschlands	BfN, DLR, RLZ,DGgaaE	Recording of Neuroptera species for nature Nature conservation/ red lists The database offers an overview of current projects and scientific data providers as well as expert support.	Free of charge	Nature conservation	https://bit.ly/3FCj5CR
Nützlinge im Garten	Bundesinformationzentrum Landwirtschaft (BZL)	The app helps to identify the most important beneficial insects and shows how to promote them.	Free of charge	Nature conservation	https://bit.ly/3tzJFJW
Pilzfürer 2 PRO and Lite	NATURE MOBILE GmbH	Practical determination and reference work of the most common mushroom species.	Subject to charge	Nature conservation	https://bit.ly/3LZIkSQ
Pl@ntNet Pflanzenbestimmung	several French institutions	With the app, users can identify one plant from a picture, and be part of a citizen science project on plant biodiversity.	Free of charge	Nature conservation	https://bit.ly/3SibhOb
Praxisapp Naturgucker	Naturgucker	The app is aimed at nature-loving people who want to record their observations outside and report them.	Free of charge	Nature conservation	https://bit.ly/3tzNwqx
Reptilien bestimmen	Coogni GmbH	Naturetouch determination of lizards, snakes, turtles etc.	Subject to charge	Nature conservation	https://bit.ly/45rYADj
Rote Liste Zentrum	BfN, DLR, RLZ	Scientific reports on the endangerment situation of species.	Free of charge	Nature conservation	https://bit.ly/45xZCNO
Schmetterlinge Deutschlands	KBS GmbH	For sharing observations about butterflies. Discoveries are displayed on the map of Germany.	Free of charge	Nature conservation	https://bit.ly/3QjuOfJ
Spinnen bestimmen	Coogni GmbH	Naturetouch determination of spiders in Central Europe.	Subject to charge	Nature conservation	https://bit.ly/46NqZVi
Tagaktive Schmetterlinge	Haupt Verlag AG	The Day-Active Butterflies app portrays 160 butterfly species that can often be found in Germany and neighbouring Central Europe.	Subject to charge	Nature conservation	https://apple.co/46to4Bt
Schädlinge (DLG)	Landwirtschaftsverlag GmbH	Digital image database for the recognition of pests on crop plants.	Free of charge	Nature conservation	https://bit.ly/3M39Yyi
Vogelführer 2 PRO and Lite	NATURE MOBILE GmbH	Identification and reference work for the most common birds in Europe.	Subject to charge	Nature conservation	https://apple.co/45Ak4Oh
Wilde Beeren und Kräuter 2 Pro and Lite	NATURE MOBILE GmbH	Determination and reference of the most common types of wild berries, fruits, herbs, and selected nuts.	Subject to charge	Nature conservation	https://bit.ly/3QecEvD
Unkräuter (DLG)	Landwirtschaftsverlag GmbH	Digital image database for the recognition of weeds in crop plants.	Free of charge	Nature conservation	https://bit.ly/46sDc1S
Wilde Tiere und Spuren 2 PRO and Lite	NATURE MOBILE GmbH	Determination and reference for the most common mammals in Central Europe and the Alps.	Subject to charge	Nature conservation	https://bit.ly/3tG0QcD

Appendix Table 17. Overview and short description of sensors (S) for agricultural work, commercially available in Germany (A–F)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
3D-Smart-Sensor O3M151 – Line Tracking	ifm electronic GmbH	Sensors based on algorithmics with e generic recognition of line-like contours and their tracking. Data interpolation available, when the contours are interrupted.	Subject to charge	Crop cultivation	https://bit.ly/3Pk3QUX
3D/2D-sensor for mobile apps (O3M251,O3M261)	ifm electronic GmbH	3D detection of scenes and objects, suited for use in mobile machines. Distance measurement and 2D camera with overlay function included. Indication of warnings and obstacles (live view).	Subject to charge	Crop cultivation	https://bit.ly/43VB9ly
Accupar LP-80 (apogee instruments)	METER Environment ®	Measures leaf area index (LAI), fractional interception and canopy growth (canopy PAR) in order to determine if water loss is from evaporation or transpiration.	Subject to charge	Crop cultivation	https://bit.ly/3JhryNS
AudioMoth (v1.0)	Open Acoustic Devices ©	Full-spectrum acoustic logger, based on the Gecko processor range from Silicon Labs. Just like its namesake the moth, AudioMoth can listen at audible frequencies, well into ultrasonic frequencies.	Subject to charge	Nature conservation	https://bit.ly/43MadVu
Baumer © sensors for agricultural equipment	Baumer Holding AG	Sensors for agricultural machines for the application areas sprayer boom height, combine header height control and implement ground clearance.	Subject to charge	Crop cultivation	https://bit.ly/469yeri
CLAAS©-Fertiliser System Isaria	CLAAS KGaA mbH	A sensor-based system for the optimised application of N-fertilisers, growth regulators or pesticides in different crops	Subject to charge	Crop cultivation	https://bit.ly/447LNFP
CROP SENSOR von CLAAS©	CLAAS KGaA mbH	Sensor with free calibration for optimal application of N-fertilisers, growth regulators/pesticides, liming.	Subject to charge	Crop cultivation	https://bit.ly/42J7pag
ecomatController CR721S	ifm electronic GmbH	Sensor signals are picked up by a central control (SPS) via decentralised sensor signals are received via decentralised modules and transmitted to the SPS via CAN-Bus - for a targeted fertilisation, e.g., when spreading slurry	Subject to charge	Crop cultivation	https://bit.ly/44mlQCD
e-obs digital tags and collars	e-obs GmbH	Lightweight GPS-tag and collars with several sensors combining high data rates for birds, mammals, and exotic species (e.g., coconut crabs). Battery and solar powered options available.	Subject to charge	Livestock	https://bit.ly/3CATCII
FS21 Sensor	Farm 21	Sensor measures air temperature, air humidity, soil moisture and soil temperature. It supports other modules of third-party sensors and global connectivity with NB-IoT, LTE-M and 2G.	Subject to charge	Crop cultivation	https://bit.ly/445zDnu
GEM-2	Geophex Ltd.	Hand-held, multi-frequency electromagnetic sensor for investigation of soil contamination from chemicals, investigation of groundwater occurrence, helping tool for precision agriculture.	Subject to charge	Crop cultivation	https://bit.ly/3NeYJmx
GPR – Ground Penetrating Radar	Sensors & Software Inc.	Control of soil water content, Application in the localisation of buried infrastructures as well as the localisation and detection of contaminant pathways	Subject to charge	Crop cultivation	https://bit.ly/42LKsDw
Grasshopper ®	True North Technologies Ltd.	Grass-cover measurement system, based on a sensor for sward height measurement.	Subject to charge	Grassland cultivation	https://bit.ly/3NAOJp3

Appendix Table 18. Overview and short description of sensors (S) for agricultural work, commercially available in Germany (S–Y)

Digital Technology name/brand	Manufacturer/Distributor	Short Summary	Availability	Application Area	Source link
SC-1 Leaf Porometer (apogee instruments)	METER Environment ®	Measurement of stomatal conductance, which tells the difference between transpiring leaves and ones that have shut down.	Subject to charge	Crop cultivation	https://bit.ly/3Pbd8Tg
SN-500 Net Radiation Sensor	METER Environment ®	Sensor measures net radiation in real time (net radiation influences evapotranspiration).	Subject to charge	Crop cultivation	https://bit.ly/3CwrbLp
SU-221 Ultraviolet (UV) Sensor	METER Environment ®	Sensor measures total radiation from 300-400 nm in- and outdoors.	Subject to charge	Crop cultivation	https://bit.ly/3NISXuV
Terahertz-Systems	TOPTICA Photonics AG	Water-contrast imaging of plant leaves - in-situ measurements of the water content of plant leaves for optimisation of irrigation strategies.	Subject to charge	Crop cultivation	https://bit.ly/3qP5ofH
TEROS-sensors	METER Environment ®	Sensors for environmental measurements: soil water content, soil temperature. Different sensor models available.	Subject to charge	Crop cultivation	https://bit.ly/3qLDkd5
Topsoilmapper (TSM)	Geoprospectors GmbH	TSM is an integrated geophysical measurement system for the determination of different soil parameters. Using geophysical measurement technology and automated analysis methodology, the uppermost soil layers (up to 1 m depth) are measured precisely and with high resolution	Subject to charge	Crop cultivation	https://bit.ly/3JhLuA1
Ultraschall-sensor RU100U	Hans Turck GmbH & Co. KG	The sensor detects the distance of the spray bars from the ground. It is acid-resistant and reliably withstands temperatures from -25 to +50 degrees Celsius and is therefore suitable for use in all climate zones.	Subject to charge	Crop cultivation	https://bit.ly/3NuDjmx
Vence®	Merck & Co. Inc.	Virtual Fencing for cattle and livestock management, which controls cattle movement, manages grazing, and creates virtual fences to dictate grazing behaviour.	Subject to charge	Livestock	https://bit.ly/3CxI2xx
Weedseeker 2	Trimble Inc.	System for pinpoint injection. Developed for impeccable weed killer, it detects resistant weeds. In the case of weeds under the sensor, it signals to the connected spray nozzle that the herbicide is precisely delivered and the weeds are destroyed.	Subject to charge	Crop cultivation	https://bit.ly/3Xbe5wF
WILDRETTTER	ISA Industrieelektronik GmbH	A machine-bound tracking system (assembly of various sensors on a boom arm at the mower), detects fawns due to their higher heat radiation of the animals compared to the meadow.	Subject to charge	Nature conservation	https://bit.ly/3JhcZtE
Winkelsensor QR20	Hans Turck GmbH & Co. KG	Sensor for site-adapted guidance of the spray boom. It measures the position of the spray arms inductively and withstands temperatures from -40 to +85 degrees Celsius.	Subject to charge	Crop cultivation	https://bit.ly/3NuDjmx
Yara N-Sensor	Yara GmbH & Co. KG	The Yara N-sensor detects with high spatial resolution how much nitrogen is supplied to the stock. From this, the required amount of fertiliser is calculated.	Subject to charge	Crop cultivation	https://bit.ly/3p8Sx7q

Appendix Table 19. Overview and short description of sensors (S) for agricultural work, commercially available in Germany (G–R)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
IRT Infrared Thermometer	METER Environment ®	Sensor for surface temperature measurements. It measures the thermal energy radiated from any surface within its field of view.	Subject to charge	Crop cultivation	https://bit.ly/3qL1W8j
Isaria Pro Active Spray	Fritzmeier Umwelttechnik GmbH & Co. KG	The sensor is an active measuring system with four high power LEDs. It can be used 24 hours a day as the system operates regardless of environmental influences such as ambient light or dew. Can also be used for pest management.	Subject to charge	Crop cultivation	https://bit.ly/43J8hx0
Isaria Pro Compact	Fritzmeier Umwelttechnik GmbH & Co. KG	Crop sensor for N fertilisation, crop appraisal and N intake scan, application of organic substance, pest management and grassland reseeding.	Subject to charge	Crop cultivation	https://bit.ly/42KxjdC
K.U.L.T. iVision PV	K.U.L.T. Kress Umweltschonende Landtechnik GmbH	Camera-controlled precision weeding instrument with sensors, the parallelogram displacement allows the rear mounting of a 3 m hoe in the lightweight ARGUS frame construction for conditions in which the use of heavy solutions is not possible.	Subject to charge	Crop cultivation	https://bit.ly/3qIH3rD
ME-Blockage	Müller® Elektronik	Sensor for monitoring of fertiliser flow in precision planters and to monitor seeding in pneumatic seeders.	Subject to charge	Crop cultivation	https://bit.ly/442sdKT
Moenit Sensor Network	Moenit GmbH	Sensor network for measurements of temperature (air, soil), humidity, soil moisture, irrigation monitoring, light measurements, pH, and EC-measurements.	Subject to charge	Crop cultivation/livestock	https://bit.ly/43L5vHs
NEXT Weather Station Basic, Eco and Pro	FarmFacts GmbH	NEXT Weather Station is the right tool for the job: an integrated system for recording, documenting, and analysing weather data, and forecasting the weather.	Subject to charge	Crop cultivation/administration	https://bit.ly/3CywOJ6
OEM-Sensors (Original Equipment-Manufacturer)	Hottinger Brüel & Kjaer GmbH	Development and production of customised sensor solutions for contact pressure, load, torque in tractors, planting and harvesting machines; sensors for seeds and fertilisers.	Subject to charge	Crop cultivation	https://bit.ly/3p5rF8p
Opto-sensor	Müller® Elektronik	Sensor for precise seed detection during seeding procedures with a sending and a receiving signal unit.	Subject to charge	Crop cultivation	https://bit.ly/3qRndL6
OptRX Plant sensor	PH.RODEN NACHF. KG	CAN-BUS based sensor for measuring of the vegetation index and enables recommendations for a needs-based fertilisation.	Subject to charge	Crop cultivation	https://bit.ly/3JjYlIm
PAR-Sensor (apogee instruments)	METER Environment ®	Full-spectrum quantum sensor that measures the Photosynthetic. Photon Flux Density (PPFD) from a field of view of 180 degrees. Outdoor and indoor sensor.	Subject to charge	Crop cultivation	https://bit.ly/3Ph7mj2
Phytos 31 (apogee instruments)	METER Environment ®	Sensor uses capacitance technology: it senses submilligram levels of water condensing on the surface, including frost and ice formation.	Subject to charge	Crop cultivation	https://bit.ly/3PhdF6f
PLANTiriumCsensor	Müller® Elektronik	Sensor for automatic seed pattern detection with status messages.	Subject to charge	Crop cultivation	https://bit.ly/3qHzFwB
PYR Sensor (Pyranometer)	METER Environment ®	Sensor measures the solar radiation flux density from a field of view of 180 degrees.	Subject to charge	Crop cultivation	https://bit.ly/3Njtc2S
Qstarz GPS Sensors	QStarz International Co. Ltd.	GPS Travel Recorder suitable for livestock pattern recognition and position monitoring.	Subject to charge	Livestock	https://bit.ly/3NaJhYo
Robocrop Side Shift System	Garford Farm Machinery Ltd.	Equipped with two cylinders, a potentiometer and a control valve, these units can be retrofitted to any hoe or mounted machine requiring precise guidance.	Subject to charge	Crop cultivation	https://bit.ly/43JizNE
RumiWatchSystem	ITIN+HOCH GmbH	Automatic system for activity and behaviour monitoring of ruminants for research.	Subject to charge	Livestock	https://bit.ly/445MtLG

Appendix Table 20. Overview and short description of field robots (FR), commercially available in Germany (A–N)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
AgBot T2, W3 and W4	AgXeed B.V.	Autonomous vehicles for soil preparation, seedbed preparation, crop management, fertiliser application. Managed via the many platforms, software, and apps.	Subject to charge	Crop cultivation	https://bit.ly/440LvQY
Autonome Feldspritze John Deere	John Deere Walldorf GmbH & Co. KG	Light autonomous sprayer, which can drive on fields after rain without causing soil compaction. High ground clearance and all-wheel steering, which enables manoeuvrability.	Subject to charge	Crop cultivation	https://bit.ly/3CAviGm
AVO – Weed robot	Ecorobotix	Autonomous field robot with solar traction and ultra-ecological spraying. It can treat up to 10 hectares per day.	Subject to charge	Crop cultivation	https://bit.ly/3qM5y7x
BoniRob	University of Applied Sciences Osnabrück/Amazone/Bosch	Field robot for stamping weeds. Imaging sensor data is transmitted from the field via internet to a telework station, where a human marks the weeds and then the weed positions are sent to the field for automated regulatory action.	Subject to charge	Crop cultivation/ administration	https://bit.ly/3Pg4V00
Carrè ANATIS Field robot	<u>Pool Agri Import & Export</u>	Fully electrically driven field robot for weeding. Completely autonomous and all-wheel steered, it works through the rows of plants based on GPS data entered in advance supported by two cameras that recognise the row of the plants.	Subject to charge	Crop cultivation	https://bit.ly/3Cy9mM7
CLAWS	Earth Rover Ltd.	A lightweight, autonomous field robot able to perform a variety of tasks such as scouting, weeding and real-time data analysis.	Subject to charge	Crop cultivation	https://bit.ly/42LCKck
Dahlia 4.3	Dahlia Robotics GmbH	Guided by artificial intelligence the robot controls an in-house build removal system towards weed plants whilst avoiding accidental damage to the crop plants. A mechanical end-effector removes the weed plants.	Subject to charge	Crop cultivation	https://bit.ly/43IZ9Zn
ETAROB	University of Applied Sciences Aachen	Autonomous agricultural robot for automating monotonous and physically demanding field work. In real time, while driving, the position of each plant relative to the tool is determined,	Subject to charge	Crop cultivation	https://bit.ly/46l3DHk
FarmDroid FD20	Farmdroid ApS	Solar-powered, fully automatic, and light weight seeding and weeding robot, usable for many crops. Sows and weeds via GPS in and between the rows, range of 20ha.	Subject to charge	Crop cultivation	https://bit.ly/3p8D8Ec
Farming GT	Farming revolution GmbH	Autonomous field robot with precise plant detection and remote monitoring via internet. Up to 30 h autonomy. Detects green already in the cotyledon stage, by day and by night.	Subject to charge	Crop cultivation	https://bit.ly/3CYaMWZ
Greenbot CR12/CR18	Precision Makers B.V.	A self-driving machine that has been specially developed to work for fruit farming, horticulture, and arable farming. It can sow, mow, plough or fertilise.	Subject to charge	Crop cultivation	https://bit.ly/3JGd1M3
JoWeeding/Multipurpose Robot	Naio Technologies	Autonomous vehicle that provides mechanical weeding, can carry tools, and has a power adapter to plug in electrical tools.	Subject to charge	Crop cultivation	https://bit.ly/3Pgn2ms
KRIBL	Universität zu Lübeck	Small robot with automated image and sensor data evaluation for autonomous navigation, detection of plant types in pasture land for small-scale farms.	Subject to charge	Grassland/ livestock	https://bit.ly/43N7QSu
MARS	AGCO GmbH, Fendt Marketing	MARS's approach is to plan, monitor and accurately document the precise sowing of maize with small, swarm-based robotic units and a cloud-based solution.	Subject to charge	Crop cultivation	https://bit.ly/448LISI
Naio Dino	Naio Technologies	Weeding robots for large-scale vegetable crops. It detects crop rows and adjusts the tools to weed as close to the plants as possible. Based on RTK GPS and other sensors.	Subject to charge	Crop cultivation	https://bit.ly/3ph9gW2
NEXT GreenSeeker	FarmFacts GmbH	Sensor and robotic equipment that can record, monitor, document and analyse data regarding weather, watering needs, biomass, distribution, pests, as well as fertilizer application and plant protection.	Subject to charge	Crop cultivation	https://bit.ly/3NxmnH

Appendix Table 21. Overview and short description of field robots (FR), commercially available in Germany (A–N).

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application Area	Source link
OMNiDRIVE™	Raven Industries, Inc.	Autonomous grain cart technology with safety cameras. Camera images run with artificial intelligence that recognises humans, animals, equipment, and other dangerous obstacles.	Subject to charge	Crop cultivation	https://bit.ly/46l87h8
OMNiPOWER™ 3200	Raven Industries, Inc.	Multipurpose power platform for autonomous seeding, spreading, and spraying. Remote command, supervision and monitoring in the field or another cab.	Subject to charge	Crop cultivation	https://bit.ly/43YNx3S
Orio Robot	Naio Technologies	A field robot with guidance system based on RTK GPS signal. This robot offers the possibility to add options for greater autonomy and precision.	Subject to charge	Crop cultivation	https://bit.ly/3PhYERr
Oz Multipurpose Robot	Naio Technologies	A field robot with guidance system based on RTK GPS signal. The robot can seed, hoe, weed, transport, assist and make furrows.	Subject to charge	Crop cultivation	https://bit.ly/3XeBwoM
Robocrop Guided Hoes	Garford Farm Machinery Ltd.	Crop imaging system which achieves row following by viewing multiple crop rows over a large area.	Subject to charge	Crop cultivation	https://bit.ly/4454ZnC
Robocrop InRow Weeder & Spot Sprayer	Garford Farm Machinery Ltd.	The system uses video image analysis techniques to locate individual plants to mechanically remove weeds from the inter row and between the plants. Developed for use on transplanted crops such as lettuce, cabbage, celery	Subject to charge	Crop cultivation	https://bit.ly/3XaAom6
Robotti (Long Range)	Agro Intelligence A/S	Field robot for high-precision, site-specific agricultural work, e.g., for vegetable growers, seed growers and trial growers: seedbed preparation, hoeing, weeding, harrowing, soil sampling, precise planting, and land management.	Subject to charge	Crop cultivation	https://bit.ly/3JigYGo
Robotti 150D	Agro Intelligence A/S	A powerful field robot for power intensive operations, with 2 engines, a PTO and traditional diesel-hydraulic setup. It can provide seeding, weeding, spraying, ridging, mowing and rotovating operations.	Subject to charge	Crop cultivation	https://bit.ly/3PhV4qH
Robotti LR	Agro Intelligence A/S	Digital infrastructure enabling automatic data collection in the field, crop as well as technical data, that can support decision support and management systems.	Subject to charge	Crop cultivation	https://bit.ly/42Fod20
Robovator Mechanical	F. Poulsen Engineering ApS.	Equipped with a camera plant detection above every row, which enables automatic hoeing in the row. It can work in darkness and can be operated by smartphone.	Subject to charge	Crop cultivation	https://bit.ly/3qJvj8h
See & Spray™ Blue River Technology	John Deere Walldorf GmbH & Co. KG/ Blue River Technology	A high-resolution camera captures 20 frames per second. Using the images and artificial intelligence, the system recognises the difference between crops and weeds. Subsequently, the individual plants are treated in a targeted manner.	Subject to charge	Crop cultivation	https://bit.ly/43KdRiI
Ted Weeding Robot	Naio Technologies	Dedicated to vineyards, the robot removes weeds mechanically.	Subject to charge	Crop cultivation	https://bit.ly/3N59ffW
Uckerbot	Zauberzeug GmbH	Robots for weed management, harvesting, inspection in the field. Additional functions are possible through additional modules	Subject to charge	Crop cultivation/ livestock	https://bit.ly/3JetzKL
Vitirover SAS	Vitirover©	Autonomous robot that detects obstacles to get as close as possible to a crop plant and cut grass around. Suitable for viticulture.	Subject to charge	Crop cultivation/ grassland	https://bit.ly/43N60ko
Warthog/Husky/Jackal	Clearpath™ Robotics	Unmanned all-terrain ground vehicles customised with sensors, manipulators, cameras.	Subject to charge	Crop cultivation/ grassland	https://bit.ly/3qDGPlx

Appendix Table 22. Overview and short description of unmanned aerial vehicles and systems (UAV/UAS), commercially available in Germany (A–V)

Digital Technology name/brand	Manufacturer/ <u>Distributor</u>	Short Summary	Availability	Application area	Source link
Agronator® e-Duster, e-Seeder®	Agronator AG	Drone for heavy-duty transport of seeds, fertilisers. Suitable for pesticide application.	Subject to charge	Crop cultivation	https://bit.ly/3Pi0dPn
Autonome Feldspritz-Drohne JD	John Deere Walldorf GmbH & Co. KG	Equipped with a weed scanner and a field syringe. This allows weeds to be scanned from the air and then specifically combated. The 10.6-litre tank is filled fully automatically in a field edge station.	Subject to charge	Crop cultivation	https://bit.ly/3p8knAO
DJI Agras T30/T10	SZ DJI Technology Co., Ltd.	Data-driven agricultural drone with a maximum payload of 40 kg. Suitable for efficient spraying and fertilising.	Subject to charge	Crop cultivation	https://bit.ly/3PA3KsH
DJI Cameras and Drones (Company)	SZ DJI Technology Co., Ltd.	Various camera drones that can capture data with high resolution.	Subject to charge	Crop cultivation	https://bit.ly/3qQ0eA5
DJI Matrice 30 Series	SZ DJI Technology Co., Ltd.	High-resolution data acquisition with dual vision and TOF sensors on all six sides. The integrated ADS-B receiver warns in good time of manned aircraft in the vicinity.	Subject to charge	Nature conservation	https://bit.ly/4637ybD
DJI Matrice 200 Series V2	SZ DJI Technology Co., Ltd	Drone platform for air workflows – high resolution data acquisition at night possible.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/3Phsohe
DJI P4P V2.0	SZ DJI Technology Co., Ltd.	Drone for high quality photos at 20 MP and videos in 4K at 60 fps with stable HD transmission and obstacle detection in five directions.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/444bLKkh
eBee X, Ag and Geo drones	AgEagle Aerial Systems Inc.	Drones for mapping with 3D, RGB, multispectral and thermal cameras.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/3N5yqis
High-End MultiKopter Drohne MK-U25	MultiKopter	Drone with a modular design for long flights with camera systems, LiDAR systems, sensors, or transport of good up to 10 kg.	Subject to charge	Crop cultivation	https://bit.ly/3Pdark5
MC8-Octocopter	AiDrones GmbH	Electrical coaxial octocopter drone with autonomous operation, designed for various applications requiring automatic operation with electro-optical payloads.	Subject to charge	Crop cultivation/nature conservation	https://bit.ly/3JiaF5E
Quanfeng Agricultural Spraying Drones	<u>Hangzhou Qifei Intelligent Technology Co., Ltd.</u>	Small and compact drone for spraying operations in different crop species, equipped with FPV camera, support AB Point Flight and a fully autonomous mode.	Subject to charge	Crop cultivation	https://bit.ly/3NC3cRD
Scout System	American Robotics	Fully-autonomous, AI-powered drone including data analysis with high resolution and real time data.	Subject to charge	Crop cultivation/grassland/livestock	https://bit.ly/42PSHhM
VoloDrone	Volocopter GmbH	Fully-electric utility drone suitable for heavy-lift-services up to 200 kg.	Subject to charge	Crop cultivation	https://bit.ly/3XeWUKX