Animal traction in an agroecological approach to the mechanisation of smallholder farming systems

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Abstract

Agroecology highlights biodiversity and mimicking natural processes to build resilient agricultural systems. Mechanisation can enhance biodiversity and lessen environmental impact when aligned with agroecological principles. In the context of draft animal power, the preference is for small-scale, low-impact machinery that supports regenerative practices. Draft animals offer a cost-effective, environmentally friendly alternative to mechanised power units for small-scale farmers, enhancing soil health through nutrient cycling of organic inputs. Advocacy and education are vital to fostering a positive perception of working animals and the benefits of draft animal use. Livestock creates a closed-loop system, where manure and compost enrich the soil, feed the plants, and support soil biota. Natural systems favour biological diversity. Incorporating draft animals into farming systems combines traditional knowledge with scientific and modern practices, contributing to sustainable and resilient agriculture. Modern draft power should utilise its mechanical advantage to generate a biological advantage for the crop. New machinery will manage the complexity and diversity of planting and harvesting multiple crops within the same space. With these capabilities, agricultural machinery aligns with agroecological principles, supporting polycropping systems while enhancing soil health.

Kurzfassung

Die Agrarökologie legt den Schwerpunkt auf Biodiversität und die Nachahmung natürlicher Prozesse, um widerstandsfähige Agrarsysteme aufzubauen. Mechanisierung kann die Biodiversität fördern und die Umweltbelastung verringern, wenn sie mit agrarökologischen Prinzipien in Einklang gebracht wird. Im Zusammenhang mit Zugtieren werden kleine, umweltschonende Maschinen bevorzugt, die regenerative Praktiken unterstützen. Zugtiere bieten Kleinbauern eine kostengünstige und umweltfreundliche Alternative zu mechanisierten Antrieben und verbessern die Bodengesundheit durch den Nährstoffkreislauf organischer Stoffe. Aufklärung und Bildung sind entscheidend, um eine positive Wahrnehmung von Arbeitstieren und den Vorteilen des Einsatzes von Zugtieren zu fördern. Vieh schafft ein geschlossenes System, in dem Gülle und Kompost den Boden anreichern, die Pflanzen ernähren und die Bodenbiota unterstützen. Natürliche Systeme begünstigen die biologische Vielfalt. Die Einbindung von Zugtieren in landwirtschaftliche Systeme verbindet traditionelles Wissen mit wissenschaftlichen und modernen Praktiken und trägt so zu einer nachhaltigen und widerstandsfähigen Landwirtschaft bei. Moderne Zugkraft sollte ihren mechanischen Vorteil nutzen, um einen biologischen Vorteil für die Pflanzen zu erzielen. Neue Maschinen werden die Komplexität und Vielfalt des Anbaus und der Ernte mehrerer Kulturen auf derselben Fläche bewältigen. Mit diesen Fähigkeiten stehen landwirtschaftliche Maschinen im Einklang mit agroökologischen Prinzipien, unterstützen Mischkultursysteme und verbessern gleichzeitig die Bodengesundheit.

Résumé

L'agroécologie met l'accent sur la biodiversité et l'imitation des processus naturels afin de mettre en place des systèmes agricoles résilients. La mécanisation peut améliorer la biodiversité et réduire l'impact environnemental lorsqu'elle est alignée sur les principes agroécologiques. Dans le contexte de la traction animale, la préférence va aux machines à petite échelle et à faible impact qui favorisent les pratiques régénératrices. Les animaux de trait offrent une alternative rentable et respectueuse de l'environnement aux unités motrices mécanisées pour les petits agriculteurs, améliorant la santé des sols grâce au cycle nutritif des matières organiques. La sensibilisation et l'éducation sont essentielles pour favoriser une perception positive des animaux de trait et des avantages de leur utilisation. Le bétail crée un système en boucle fermée, dans lequel le fumier et le compost enrichissent le sol, nourrissent les plantes et favorisent les biotes du sol. Les systèmes naturels favorisent la diversité biologique. L'intégration des animaux de trait dans les systèmes agricoles combine les connaissances traditionnelles avec les pratiques scientifiques modernes, contribuant ainsi à une agriculture durable et résiliente. La traction moderne devrait utiliser son avantage mécanique pour générer un avantage biologique pour les cultures. De nouvelles machines permettront de gérer la complexité et la diversité de la plantation et de la récolte de plusieurs cultures dans un même espace. Grâce à ces capacités, les machines agricoles s'alignent sur les principes agroécologiques, soutenant les systèmes de polyculture tout en améliorant la santé des sols.

Resumen

La agroecología se centra en la biodiversidad y en imitar los procesos naturales para crear sistemas agrícolas resilientes. La mecanización puede mejorar la biodiversidad y reducir la contaminación del medio ambiente cuando se ajusta a los principios agroecológicos. En el contexto de la tracción animal, se prefiere la maquinaria a pequeña escala y inofensiva para el medio ambiente que favorece las prácticas regenerativas. El ganado de tiro ofrece una alternativa rentable y respetuosa con el medio ambiente a las unidades de tracción mecanizadas para los pequeños agricultores, ya que mejoran la salud del terreno mediante el ciclo de nutrientes de los insumos orgánicos. La promoción y la educación son fundamentales para fomentar una percepción positiva del ganado de tiro y los beneficios de su uso. El ganado crea un sistema de ciclo cerrado, en el que el estiércol y el compost enriquecen el terreno, alimentan las plantas y favorecen la biota del terreno. Los sistemas naturales favorecen la diversidad biológica. La incorporación del ganado de tiro en los sistemas agrícolas combina los conocimientos tradicionales con las prácticas científicas y modernas, contribuyendo así a una agricultura sostenible y resiliente. La tracción moderna debería aprovechar su ventaja mecánica para obtener una ventaja biológica para las plantas. La nueva maquinaria superará la complejidad y la diversidad del cultivo y la cosecha de múltiples cultivos en la misma superficie. Con estas capacidades, la maquinaria agrícola se alinea con los principios agroecológicos, apoyando los sistemas de policultivo y al mismo tiempo mejorando la salud del terreno.

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Agroecological approach to mechanisation and the role of draft animals in farming systems

Agroecology emphasises biodiversity and mimicking natural processes to develop resilient agricultural systems. Agroecological approaches are viewed as production systems rather than merely technologies. Diverse ecosystems are more resilient to environmental changes, improving agriculture's ability to adapt to climate change and other challenges. Mimicking natural processes and promoting biodiversity helps these systems respond to disturbances and naturally control pests. Refer to Wenzel et al. and HLPE for an extensive review of agroecological practices for sustainable agriculture, such as crop rotations, intercropping, relay cropping, and tillage management[1].

An editorial published in Nature[2] cites the international research consortium Ceres2030[3], reporting that out of approximately 570 million farms worldwide, more than 475 million are smaller than two hectares. Animal power is a crucial component of many small farms. In an agroecological approach, animal power is evaluated within social, cultural, and economic contexts. Modern draft animal power considers environmental and ecological factors, combining local knowledge with science and modern practices, and fostering resilient and sustainable farming systems. In practice, draft animal power often complements traditional knowledge and practices. Preserving and applying this knowledge can enhance ecological benefits. Crop yields in response to inorganic and commercial fertilisers are diminishing, and research has shown substantial yield benefits when combining inorganic fertilisers with organic nutrient sources. Livestock creates a closed-loop system where manure and compost enrich the soil, feed the plants, and support soil biota. Their manure is a natural fertiliser and source of organic matter, cycling crop nutrients, building soil health, and reducing reliance on commercial fertilisers.

Healthy, productive soil forms the basis of a successful farming system. The moderate hoof action of livestock can stimulate plant growth by gently stressing the plants, prompting them to regenerate and grow more vigorously, which results in increased root biomass. As animals move across a field, they deposit manure rich in organic matter and nutrients while trampling grass, leaves, and other plant materials. Animal hoof action helps build up soil organic matter through processes like incorporating plant material, compost, and manure, which stimulates soil biology, improves soil aeration, promotes root growth, enhances soil aggregation, creates microhabitats for microorganisms, and encourages a diverse plant community. However, excessive and prolonged hoof traffic can compact the soil and harm its physical properties.

Draft animals can be a cost-effective alternative to wheeled vehicles for small-scale farmers[4]. Several features of agricultural machinery are custom-built for draft animals, ensuring that the equipment is efficient, safe, and suitable for use with horses, oxen, donkeys, or mules. These features balance the animals' capabilities and welfare with the efficiency and functionality required by those operating them. The hitching system, including yokes, collars, and harnesses, is designed to be comfortable and safe, distribute the load evenly, absorb shocks, and minimise the risk of injury or discomfort.

Over-cultivation and over-grazing degrade soils. Restoring and enhancing soil fertility is a concern widely shared by smallholder farmers. Crop yield responses to inorganic and commercial fertilisers are diminishing, and research has demonstrated substantial yield benefits when combining inorganic fertilisers with organic nutrient sources such as manure and compost. Mixed crop and livestock systems support soil health and build biological soil fertility. Integrating crop and livestock systems offers an opportunity to improve soil health and promote sustainable intensification. Livestock-based cropping systems enhance soil fertility and crop yield by cycling nutrients from manure, compost, and cover crops.

Our approach is agroecological - a production system, not a simple tillage or planting technology. Machines are part of a broader system where ecological and social benefits are valued and sought after. Designing agricultural machines to promote polycropping and soil health involves creating equipment capable of managing the complexity and diversity of planting, crop care, and harvesting multiple crops in the same area. Machines should be compatible with low-disturbance tillage and crop residue cover and operate in fields with cover crops, including planting main crops without completely removing the cover crops. With these capabilities, agricultural machinery aligns with agroecological principles.

Soils and cropping system mechanisation

Mechanisation can reduce the workload of conducting farming operations profitably on small farms. Soils influence the design of appropriate-scale mechanisation and cropping system management. Understanding and managing soils is crucial for selecting suitable crops and maintaining soil quality and health.

Fundamentals of soils

You will often hear some key terms describing soils. *Soil quality* refers to the ability of the soil to carry out ecological functions and provide ecosystem services that benefit humans by providing clean air and water and sustaining soil resources. Soil quality parameters such as water infiltration rate and aggregate stability are measurable and quantifiable. Cropping and management practices can enhance or diminish soil properties such as aggregate stability, water infiltration rate, nutrient cycling, and the diversity of soil organisms.

Soil health differs from soil quality. It concerns how soil functions within an ecosystem and is difficult to measure with a single parameter. Soil health indicates biological integrity, a balance among soil organisms, resilience to recover from environmental stress, and the capacity to provide ecosystem services such as protecting water quality, maintaining soil biological fertility, nutrient cycling, soil formation, and supporting biodiversity.

1 Wenzel et al. 2014; HLPE 2019.
2 To end hunger 2020.
3 Laborde et al. 2020.
4 Harrigan 2022.

Fig. 1. *Livestock cycle crop nutrients, and the moderate hoof action of livestock can stimulate plant growth, resulting in greater root biomass (Picture: T. Harrigan).*

Soil texture refers to the relative proportions of sand, silt, and clay. It influences the choice of tillage and cropping systems. Clay soils should not be worked when wet, but they resist wind erosion. Sandy soils are prone to blowing and benefit from cover crops and conservation practices to prevent wind erosion. Some crops adapt to slow drainage and poor aeration, while others need loose, friable soils and irrigation for good yields. Coarse-textured soils have low moisture-holding capacity, and drought often limits production more than on finer-textured soils, but they are easier to work with.

A *soil aggregate* is a mass of fine soil particles glued together by clay, organic matter, and microbial and root exudates. Soil aggregation is a sign of soil quality and soil health. Naturally occurring aggregates are called peds. Soil aggregation enhances permeability and encourages root growth, soil aeration, and water infiltration. Soil aggregates resist wind and water erosion. Excessive tillage and traffic break down the aggregate structure and reduce the soil's ability to recover from external stressors such as tillage and vehicle traffic.

Soil organic matter serves as an indicator of soil quality and is a vital component of soil health. Organic matter consists of material from plants and animals that forms humus, a dark-coloured and decay-resistant residue resulting from organic matter decomposition. Soil organic matter and humus are essential for forming and stabilising soil aggregates, providing a significant source of plant nutrients, and supporting soil biological activity. They also play a crucial role in water retention, drought resistance, and soil resilience.

Annual additions of organic material are essential to increase or sustain soil organic matter in most managed cropping systems. New organic materials support soil microbes and release crop nutrients. Green manures, cover crops, livestock manure, and compost are organic inputs that can replace crop residues and soil organic matter lost to the cropping system. Plants grow easily in moist soils, and because soil aeration is poor in wet areas, decomposition is slow, leading to greater organic matter accumulation than in dry soils.

Fig. 2 *The in-line strip tiller loosened and firmed the soil in a narrow planting zone, retaining protective crop residues between the rows (Picture: Maria Jones).*

Frequently tilled, well-aerated upland soils often have conditions favourable to excessive microbial activity and organic matter oxidation (loss). Increasing or maintaining natural organic matter levels under conventional management of such soils is challenging. Crop residues act as mulch and help build soil organic matter by keeping the soil cool and moist. Mulches like straw add organic matter, suppress weeds, moderate soil temperature, reduce evaporation, retain soil moisture, and decrease soil erosion from overland flow. While crop residue may be harvested for feed, animal bedding, fuel, or burned to simplify certain cropping practices, the overall result is the loss of soil organic matter.

Continuous row cropping and moldboard plough-based tillage systems generally lead to the most significant decline in soil organic matter. Small grains are less harmful. Well-managed pasture or hay crops can increase organic matter levels. No-till and low-disturbance tillage are less disruptive than the moldboard plough and disk harrow. Strip tillage confines soil disturbance to narrow bands for seedbeds and retains protective crop residue between rows. Crop residues create a mulch or protective soil cover. The residue shields the soil from raindrop impact, slows water movement to enhance infiltration, and conserves moisture for crops by reducing surface evaporation.

Evolution of tillage implements.

Tillage involves working the soil to improve growing conditions. It can help incorporate soil amendments like lime and fertiliser, manage crop residues, relieve compaction, improve water infiltration, prepare a seedbed, and control weeds. In the U.S., early farmers mainly used hand tools. Even today, many smallholder farmers in sub-Saharan Africa prepare the soil with hand tools and hope to access draft animals for field work and transport. Globally, draft animals remain essential in reducing the labour of field work and increasing the productivity of small-scale farmers.

Many growers notice that crop yields often improve after tillage, which helps loosen the soil. Conventional (intensive) tillage practices leave less than 15% of the soil surface covered with protective crop residue after planting the next crop. The mouldboard plough is one of the most aggressive and intensive tillage implements. Some growers perform 'skim' ploughing at a depth of five to eight centimetres to minimise the negative impacts of deeper soil disturbance. Moldboard ploughing is decreasing on most US farms unless specific soil conditions favour it, although it remains widely used on small farms worldwide. Conservation tillage refers to cropping systems that retain more than 30% of surface residue cover after planting. Examples include no-tillage, mulch-tillage, and strip-tillage. Current cropping systems have evolved to focus more on soil biological health. In the U.S., the Natural Resource Conservation Service (NRCS) uses the Soil Tillage Intensity Rating (STIR factor) to classify the intensity of soil disturbance after tillage. The STIR factor considers the type of tillage tool, depth, speed, and the percentage of surface area disturbed.

Fig. 3 *Mono-cropping evolved to make planting, weeding, and harvest mechanisation more efficient. Modern machines will be compatible with poly-cropping systems such as inter- and relay-cropping (Picture: T. Harrigan).*

From a management perspective, the main goals of soil conservation include creating conditions for rapid water infiltration, reducing the volume and speed of water runoff and overland flow to decrease sediment transport, and covering the soil with protective crop residues or vegetative cover to keep it stable. Conservation tillage aligns better with agroecological objectives than intensive tillage with the mouldboard plough. The 'clean', residue-free tillage based on the mouldboard plough and disc harrow was the primary cause of wind and water erosion that devastated the American prairies in the 1930s and continues globally. Inversion tillage removes the protective vegetative barrier, destabilising the soil surface. Topsoil is the most productive and biologically active layer, containing most organic matter and vital plant nutrients. Exposed soil is vulnerable to topsoil loss. When soil erosion happens, particles can carry away nutrients, sediment, and other pollutants that contaminate lakes and streams and harm soil health.

Intensive tillage loosens and warms the soil, buries crop residues, and injects excess oxygen, accelerating the oxidation and loss of humus. Close contact between crop residues, soil microorganisms, moisture, and oxygen promotes rapid decay that quickly consumes new organic material. Conservation tillage, especially no-till, concentrates organic matter in the top few centimetres of the soil. This improves moisture infiltration, reduces crusting and erosion, and makes nutrients available where roots are most abundant. Purposeful, sustainable systems such as organic and biodynamic farming focus on extensive livestock management, crop rotations, and biological nitrogen fixation to build organic matter and improve soil health[5]. Sustainable cropping practices minimise soil disturbance, maintain a protective vegetative or residue cover on the soil surface, and add organic inputs from manure, compost, and cover crops.

Mechanisation can enhance or detract from an agroecological approach, depending on how it is implemented and managed. Incorporating ecological principles into machinery design and management aligns mechanisation with agroecological objectives. Mechanisation should support regenerative practices; small-scale, low-impact equipment is often most suitable. Well-designed machines minimise their environmental footprint by reducing soil disturbance, promoting biodiversity, and mitigating negative impacts. Collaborating with draft animal practitioners can inspire innovation in machinery design and ensure the machines align with agroecological principles.

Fig. 4 *Strip-till planting zones minimise soil disturbance and are compatible with agroecological principles (Picture: T. Harrigan).*

Mono-cropping evolved to make planting, weeding, and harvesting more efficient. Mechanisation often conflicts with poly-cropping systems, such as inter- and relay-cropping, which recognise the inherently biological nature of agriculture. There is a need to develop machines capable of managing the complexity and diversity of planting and harvesting multiple crops in the same area. Additionally, there is a need for machinery that is appropriately sized and suited for work in fields with cover crops, including the ability to plant main crops without completely uprooting the cover crops. With these capabilities, agricultural machinery aligns with agroecological principles, supporting polycropping systems while enhancing soil health.

5 Stockdale/Cookson 2003.

Mechanisation technologies

The agroecological approach we adopted in West Africa enhanced sustainability and addressed environmental, financial, social, and cultural dimensions. This method can be applied to any region using animal traction. Animal-powered, appropriate-scale mechanisation was crucial in increasing agricultural productivity, boosting farm and household incomes, and reducing the physical labour demanded of women and children. The process involved linking science and engineering with local social and cultural knowledge.

The functional component of draft animal power is the tool or implement. Tools and implements are mechanical systems. There is a need to utilise the mechanical advantage of machines to promote soil health and create a biological benefit for the crop. An agroecological approach values low-disturbance tillage, protective crop residue, organic inputs, biological diversity, and active root systems. Introducing new machines often leads to redesigning the farming system, requiring changes in subsequent operations, such as using the sweep cultivator for full-width weed control and soil loosening instead of a mouldboard plough. The timing of field operations may also need to change. For instance, earlier weed control and timing the first field operations to synchronise with rain events when the soil is soft and friable whereas the traditional practice was to schedule hand-weeding at 21-day intervals. Our work achieved the best results with the animal-drawn sweep weeder aligned with the biological intervals of weed emergence and growth. Numerous ripple effects occur when initiating changes in cropping and farming systems, necessitating adaptations, which are often required during the redesign process.

Cropping system: in-line ripper, low-disturbance planter, sweep cultivator.

In sub-Saharan Africa, the soils are highly weathered and have low natural fertility. Small-scale farming and low farm incomes predominate. The moldboard plough is the primary tillage tool. We adopted a pragmatic approach to improve the lives of poor, smallholder farmers. Animal traction suits local conditions well. Our innovations, such as affordable planters and strip-tillage rippers, have increased crop yields and saved time, especially for women. This approach aligns with the local physical, social, and economic realities, prioritises affordability, builds local capacity for machine innovation, manufacturing, and repair, and empowers farmers with adaptable options within their means.

Our main aim was to decrease intensive tillage and start restoring soil health and natural soil productivity. We combined local knowledge and experience with equipment design to support integrated practices, such as low-disturbance tillage with in-line rippers for strip tillage, shallow sweep tillage for seedbed preparation, and weed control. We redesigned planters for low-disturbance tillage and residue management. We trained local artisans to build and repair machines, source materials locally, craft specialised seed plates, and design furrow openers and closers for low-disturbance strip tillage. This approach benefits smallholder farmers by conserving soil moisture, reducing tillage intensity, saving time and labour, and maintaining crop residue cover on the soil surface.

Fig. 5 *Local artisans built a furrow opener for residue-clearing and consistent seed depth, and furrow closers and press wheels adapted for low-disturbance, soil-stabilising in-line strip tillage (Picture: T. Harrigan).*

Working with local farmers, we redesigned the local farming system by introducing an innovative in-line ripper for strip tillage to replace the moldboard plough. A key improvement was a rolling basket behind the ripping shank to break up soil clods and level the seedbed within the narrow, tilled zone. The ripper tills a narrow band of soil about 20 cm wide and 15 cm deep, retaining protective crop residues between the rows and capturing water as the rainy season begins. In fields with minimal weed pressure, this innovation reduced cost compared to a moldboard plough by replacing the solid steel main beam with an open web truss design fabricated from locally available materials.

The draft, or pulling force required of the draft animals, decreased by half compared to a plough, from an average of 93 kilograms-force (kgf) to 43 kgf for the in-line ripper. The 54% reduction in draft is significant because most draft animals lose body condition during the dry season and are in poor working condition at the start of the tillage and planting season. With the in-line ripper, they can cover the same ground with less effort, or more ground with the same effort, enabling faster planting and weed control. The animal's physical condition and productivity improve as the rainy season brings abundant forage. The cost of the in-line ripper in 2020 was FCFA 25,000 (38€).

Low-disturbance, minimum tillage planter

Our work introduced innovations, including a planter, which significantly improved seed placement, reduced bird predation, and increased crop yield by 50-150% compared to hand planting. Recognising deficiencies in earlier planter designs, including a French-derived planter from Mali and models commonly used in Brazil, we developed a new planter suitable for the region. The planters imported from Mali were costly, intended for intensively tilled seedbeds, and poorly suited for fields with soil clods and crop residues.

Fig. 6 *Compared to hand-planting, the seeds were placed at a uniform depth and consistent spacing; seeds germinated faster and emerged uniformly (Picture: T. Harrigan).*

We trained local artisans to build a planter featuring a low-cost seed-plate drive mechanism, a furrow opener for residue-clearing and maintaining consistent seed depth, along with furrow closers and press wheels adapted for low-disturbance, soil-stabilising in-line strip tillage. An innovative furrow opener ensured precise seed placement. Small concave disc furrow closers replaced high crown sweeps, aiding crop residue flow. Among the redesigned components was a narrower press wheel optimised for the narrow tillage zone created by the in-line subsoiler.

The planter innovations greatly enhanced maize planting efficiency. The planter's mechanical advantage improved the maize crop's biological efficiency. Compared to hand planting, seeds were uniformly placed at the same depth and spacing; germination was quicker, and emergence was more uniform. Side-by-side grain yield comparisons in farmers' fields showed a significant yield benefit from machine planting over hand planting, ranging from 50% to 150%. Much of this increase was due to less seed loss to birds. Birds can easily find and steal seeds planted by hand, but cannot easily locate seeds planted by machine. The average draft of the planter was 20 kgf, which is manageable for even a single donkey, the draft animal most preferred by women farmers[6].

Mechanical weed control

Effective weed management is essential for profitable crop yields. Weeds compete with crops for water, sunlight, and nutrients, harbour pests, and can be toxic to livestock. Controlling them is burdensome for smallholder farmers as it requires considerable labour and resources. Early-season weed control is crucial; small, young weeds are easier to uproot before establishing extensive root systems.

Fig. 7 *Low-crown, low-pitch cultivator sweeps under-cut weeds and loosens the soil, reducing cultivator draft and improving weed control (Picture: T. Harrigan).*

In Africa, weed control choices depended on weed pressure, often requiring multiple cultivations. Traditionally, farmers used locally built five-shank cultivators, relying on deep and aggressive soil disturbance to uproot and bury weeds. However, this design had three significant problems: 1) clogging with crop residue, 2) high draft (pulling force), and 3) inadequate weed control due to insufficient root cutting. Our lead farmer removed two of the five shanks to address these challenges and used only three to improve crop residue flow and prevent plugging. However, the draft remained high, similar to the moldboard plough, and weed control was poor.

We addressed the challenges of high draft and poor weed control by designing a locally made, low-crown, low-pitch sweep cultivator that effectively undercuts weeds while preserving protective crop residues on the soil surface. These low-pitch sweeps covered most of the interrow area at a shallow depth of about five centimetres. They improved weed control and enhanced the cultivator's stability and ease of use for farmers. They increased the productivity and effective width of root cutting by 20%, lowering the cultivator's draft by 22%, from 93 kgf to 73 kgf, compared to the three-shank cultivator.

Fig. 8 *When soil conditions are suitable, the sweep cultivator can replace the moldboard plough, saving time and labour, and retain crop residues on the soil surface (Picture: T. Harrigan).*

6 Pousga et al. 2025; Scheidweiler 2022.

The sweep weeder alone proved effective for shallow weed control, residue retention, and creating a suitable planting bed in moist and friable soils after early-season rains. This method eliminated the need for the mouldboard plough and minimised soil disruption, reducing both time and labour to just a third of traditional ploughing. Sweep tillage aligns with our agroecological approach by maintaining low-disturbance tillage and crop residue to restore soil quality and health. These broad, flat sweeps operate at a shallow depth of 5 cm, undercutting weeds and slicing through roots just below the soil surface while causing minimal disturbance to the soil structure. Shallow sweep tillage conserves protective crop residues, decreases tillage intensity, retains soil moisture, and enhances soil health. It will be crucial for smallholder farmers to transition from the mouldboard plough and adopt an agroecological approach to improve soil health, natural soil fertility, and crop yields.

Precision mechanical weed control

Innovations in weed control technology, such as developing low-crown and low-pitch sweeps, have further optimised weed control and seedbed preparation. These updated designs enable full-row width root cutting at a shallow depth, effectively undercutting weeds while causing less soil disturbance than traditional high-crown sweeps. For seedbed preparation, sweeps create an even, friable surface by removing weeds and breaking up soil clods without inverting the soil. By retaining valuable moisture and organic matter in the topsoil layers, sweeps prepare a seedbed conducive to seed germination and root growth, aligning well with agroecological objectives.

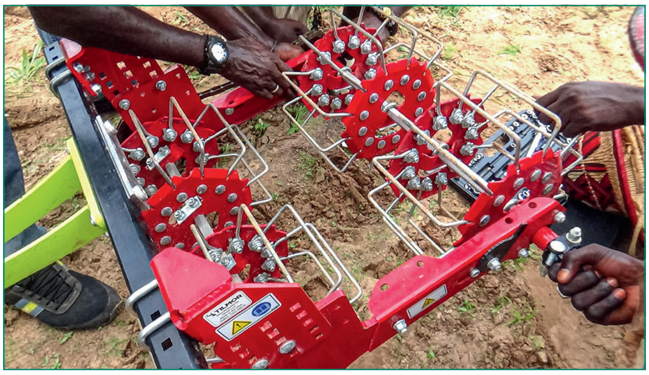

***Fig. 9** Modern weeding tools can be adapted for animal traction. This basket weeder, coupled with a finger weeder and spyders, works well within and between the rows (Picture: T. Harrigan).*

Well-designed weeding tools are essential, each suited for different crop growth and weed development stages. Modern weeding tools like flex-tine and basket weeders are effective during early weed stages, functioning best on loose soil and dry conditions. Spyders work well between and close to the row for burying small weeds within the row. Finger weeders are useful for larger, well-rooted crops, targeting plants between and within the row without harming the crop. These modern weed removal tools require precision and control to avoid damaging the growing crop. These implements can be adapted for animal draft, highlighting modern animal traction's relevance.

Integrating diverse weed management strategies, timely interventions, and innovative tools can boost weed control, increase crop yields, and lessen farmers' workloads. Precision mechanical weed control promotes sustainable agriculture by reducing chemical inputs, effectively managing weeds, and lowering tillage intensity. This approach combines new tools with a comprehensive understanding of the soil-crop-weed ecosystem. It embodies an environmentally conscious and ecologically friendly approach.

Improving the perception of draft animals

The public perception of draft animal use is an important topic worth discussing. Draft animals are often seen as outdated or inefficient in areas with access to modern machinery. However, well-trained animals can demonstrate the precision required for modern farming practices. Advocacy and education will be essential to foster a positive perception of working animals and the benefits of draft animals. Employing draft animals helps preserve traditional skills, such as horse or oxen training, harness and yoke making, and farming techniques. Working with draft animals can improve soil health, and engaging with them provides hands-on learning opportunities, especially for younger generations, to understand agriculture, history, and animal care.

***Fig. 10** Demonstrations of ploughing, planting, and harvesting can present a modern vision of draft animals, showcasing their efficiency, precision, and practicality, and their role in sustainable agriculture and soil health (Picture: T. Harrigan).*

There is an increasing recognition of the disconnect between humans and the natural environment. Hands-on experiences reconnecting people with nature are in high demand and highly valued. Working with draft animals offers a direct link to nature and the land. Engaging with draft animals provides a holistic learning experience, emphasising emotional intelligence and practical skills.

Refocusing public perception of working with draft animals to value their positive benefits will require education and awareness, while emphasising their practical, environmental, and cultural advantages. Demonstrations of ploughing, planting, and harvesting with draft animals can showcase their efficiency, precision, and practicality, highlighting their role in sustainable farming and promoting soil health, which will resonate with environmentally conscious audiences.

Conclusions

Agroecology emphasises biodiversity and mimicking natural processes to develop resilient agricultural systems. Mono-cropping evolved to make planting, weeding, and harvesting more efficient. Mechanisation often conflicts with poly-cropping systems, such as inter- and relay-cropping, which acknowledge the inherently biological nature of agriculture. Tillage and planting methods have evolved from intensive soil disturbance with no protective surface crop residue to conservation tillage and residue management, to a focus on soil biological health with minimal soil disturbance, extended rotations with living cover crops and active root systems, plant and soil biodiversity, and natural soil fertility. Designing agricultural machinery to support polycropping and soil health involves creating equipment capable of managing the complexity and diversity of planting, crop care, and harvesting multiple crops in the same area. Machinery should be compatible with low-disturbance tillage and crop residue cover and operate in fields with cover crops, including planting main crops without entirely removing the cover crops. Draft animals provide a cost-effective, environmentally friendly alternative to mechanised power units for small-scale farmers, promoting soil health through nutrient cycling of organic inputs. Working with draft animals can enhance soil health, and engaging with them offers practical learning opportunities—especially for younger generations—to gain knowledge about agriculture, history, and animal care.

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