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Mechanized cover crop farming: Modern methods, equipment and technologies

Ovundah King Wofuru-Nyenke*

Department of Mechanical Engineering, Rivers State University, Port Harcourt, Rivers State 500264, Nigeria
* Corresponding author, E-mail: ovundah.wofuru-nyenke@ust.edu.ng

Abstract

Cover crops are important for covering the soil and fixing nutrients in order to manage soil erosion and improve soil quality. This paper discusses some of the modern methods, equipment and technologies used in carrying out cover crop farming. This is important because modern agricultural and farming operations work a lot differently from those of the past as a result of the improvements in technological advancements over the past decades. The paper explains the usefulness of the various classes of cover crops known as grasses, legumes, brassicas and non-legume broadleaves. It also explains the role of smart farming technologies such as artificial intelligence and big data, satellites, drones and robotic systems as well as Internet of Things (IoT). Some of the benefits of these advanced technologies are high crop productivity, efficient use of water, fertilizer and pesticides, and improvement in farmer safety and growing conditions, as well as reduced impact on the natural environment and ecosystem. Mechanized cover crop farming equipment are also discussed, and grouped into preparation, planting, termination and incorporation equipment, based on the stage they are used during the cover crop farming process. Clearly, these advanced equipment and technologies are aiding the cover crop farming process by making it safer and environmentally friendly while helping farmers to be more efficient.

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Introduction

Agriculture is responsible for providing the food, raw materials and fabrics of the world. It is the art and science of cultivating the soil, growing crops and raising livestock[1]. Before the widespread growth of agriculture, humans spent most of their lives as nomads gathering wild plants and hunting wild animals[2]. When people started growing crops, they also began herding and breeding wild animals, thereby adapting and domesticating wild plants and animals for people to use. Humans have domesticated numerous plants such as rice, corn etc, as well as animals such as dogs which have in turn been used to hunt and domesticate sheep, goats, cattle, pigs etc.[3] which are now sources of meat, milk, cheese and butter. Over time, farmers started using their domesticated oxen, horses, donkeys and camels for plowing, pulling and transportation[4]. Today, there are various modern machines and equipment making agriculture easier, thereby helping people to produce excess food used for trading or subsistence[5].

Crop farming is the process of working the ground, planting seeds and growing plants[6]. A crop can be planted for harvesting and subsequent use for subsistence or sale. However, cover crops are planted not for harvesting, but for covering the soil, preventing wind and water erosion, leaching, nutrient loss and generally improving soil health and quality[7]. Other advantages of cover crops include reduction in fertilizer costs, reduction in need for herbicides and other pesticides, safeguarding of personal health, conservation of soil moisture, and protection of water quality[8]. Therefore, cover crops are used by farmers because of the multiple benefits they contribute to soil and crop management systems.

Farmers usually encounter common agricultural challenges such as soil erosion, biodiversity losses and demand for higher quality crops. Cover crops serve to naturally stem soil erosion while fixing nutrients into the soil and encouraging growth of various organisms. Therefore, the aim of this study is to describe the modern methods, equipment and technologies which exist for making the cover crop farming process easier. These technologies serve to improve crop yield, reduce soil quality depletion, reduce manual labor and lower financial costs. They include artificial intelligence and big data, satellites, drones and robotic systems as well as Internet of Things (IoT). The central benefit of these technologies is that they give the farmer the ability to monitor farmlands in real-time without the need to be present on the field. Though these technologies have not been widely adopted by farmers as a result of the cost of implementation, farmers who have adopted them are experiencing benefits in leaps and bounds. The study also describes some modern cover crop farming equipment which are useful for reducing manual labor and saving production costs and time. These mechanized cover crop farming equipment can be grouped into preparation, planting, termination and incorporation equipment, depending on the stage they are used during the cover crop farming process.

Usefulness of cover crops

The use of cover crops dates back to the late 1700s when lupines were used throughout northern Europe for improvement of sandy soils. In those years, farmers cultivated their land for extended periods and observed that the soil eroded and became less fertile. Since synthetic fertilizers were not as rampant[9], they implemented cover crop farming on their land to replenish soil quality. Between the 1860s and 1950s cover crop farming was widely practiced in farming, but was later abandoned in the late 1950s when conventional agriculture resorted to using synthetic fertilizers to improve soil quality[10].

Some common modes of growing cover crops include growing them all through the year as a living mulch also known as 'planting green', planting the cover crops after harvest of cash or subsistence crops or intercropping the cover crops between rows of the cash or subsistence crop. Green-planted farmlands are beneficial for moisture management in situations of wet soils or when weed control is required. According to the 2020 Sustainable Agriculture Research and Education (SARE) survey[11] consisting of 1,172 farmers, 52.5% reported that they had planted green, in an effort to better manage wet soils. Among the farmers that planted green, 68% indicated that they had better soil moisture management. As a matter of fact, 54.3% of the respondents reported that they were able to plant cash crops sooner in their green-planted farmlands than in farmlands with early cover crop termination or absence of cover crops. This can be explained by the fact that the growing cover crops actively transpired moisture from wet soils. Additionally, 70.5% of respondents reported that planting green improved weed control. However, the planting green practice has its disadvantages which include difficulty in controlling pest snails, slugs and rodents which damage plant seeds, seedlings, fruit, leaves and underground tubers. This subsequently results in the death of the plant and major production losses. Therefore, successful cover crop farming is based on selecting the appropriate mode of growing the cover crops, as well as selecting the species or mixture of species that achieve the soil quality goals of the farmer.

Farmers are often faced with the decision of selecting the most beneficial cover crop or cover crop combination that will impart the required benefits to the soil and ecosystem. Cover crops can be classified into four main classes known as grasses (e.g. ryegrass, rye, wheat, triticale, oats, barley, forage sorghum and millet), legumes (e.g. soybean, cowpea, sunn hemp, alfalfa, clovers, faba bean, hairy vetch, lentil, medics, pea and serradella), brassicas (e.g. mustards, kale, rapeseed, radishes and turnips) and non-legume broadleaves (e.g. buckwheat, phacelia, safflower, sunflower, spinach and flax)[12]. Therefore, cover crop selection decisions are based on specific situations and the distinct benefits obtained from the various classes of cover crops. Cover crop residue have been known to enhance organic carbon, nitrogen, phosphorus, potassium, calcium, iron and magnesium[13].

Grasses are very useful for absorbing nutrients such as nitrogen left over after harvesting a previous crop. Their roots are also useful for adding organic matter to the soil while the large amounts of aboveground residue they produce can help suppress weed germination and growth, and can also be incorporated into the soil. The residue from grasses are available for a longer period of time than that of legumes because grasses are higher in carbon[14]. However, the high carbon to nitrogen ratio of grasses poses a major disadvantage common to all grasses because when they are grown to maturity in order to obtain the maximum amount of residue, the available nitrogen in the soil for the next crop becomes substantially depleted.

Legumes are used to fix atmospheric nitrogen into the soil through the root nodules which contain nitrogen-fixing bacteria known as *Rhizobium* spp. Since these legumes are higher in nitrogen than grasses[15], their residue breaks down faster than other cover crops. Therefore, planting legumes as cover crops can help farmers save money on fertilizers that improve the Nitrogen content of the soil, while reducing the negative impact of synthetic fertilizers on the environment. However, the combination of legume and grass cover crops on a farmland combines the benefits of each class of cover crop creating the synergistic benefits of nitrogen scavenging, biomass production as well as weed and erosion control.

Brassicas are not as popular as grasses or legumes, however, they are potent absorbers of excess nutrients in the soil from the previously planted crop. Their large taproots aid in easing soil compaction. Brassicas are also useful for their natural pest management and biofumigation characteristics, as they release toxic chemical compounds known as glucosinolates, which can be broken down into isothiocyanates by hydrolysis with the myrosinase enzyme[16], and are harmful to pests and pathogens in the soil. However, the planting of brassicas should not be used as the only source of pest control, as they are less effective than commercial pesticides. The usefulness of brassicas as cover crops have been reported in several studies[17−20].

Non-legume broadleaves are useful in many ways especially their ability to improve soil structure by decreasing soil compaction, improving soil aeration and improving water infiltration because of their tap roots that create voids through the soil. They are desirable to farmers for their rapidly decomposing residue which releases nutrients into the soil, providing fertility to improve the soil. They are also desirable to insect pollinators such as beetles, moths and butterflies, as a food source. Figure 1 shows the various classes of cover crops.

Farmers also tend to mix multiple cover crops species to obtain several benefits of the various cover crop classes. As stated earlier, mixing species can provide benefits such as nitrogen scavenging, biomass production as well as weed and erosion control. The idea behind mixing cover crops is that at least one or a few species will thrive during the season and aid in suppressing weeds, controlling erosion and improving soil

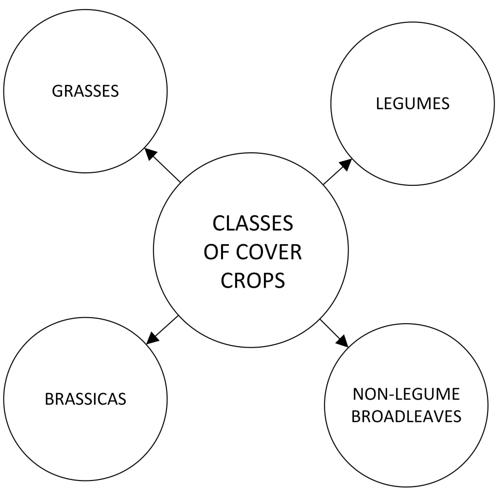

Fig. 1 Classes of cover crops.

properties[13]. Several studies have shown the importance of blending multiple cover crop species as well as the appropriate strategies and nutrient ratios[20−26].

Table 1 shows the common cover crops and their scientific names. The cover crops have been grouped according to their classes for easy identification.

Modern farming technologies

Over the years, agricultural practices have continuously improved with the aim of improving crop yield while ameliorating soil quality depletion, reducing manual labor and lowering financial costs. Some common agricultural challenges for farmers include soil erosion, biodiversity losses and demand for higher quality crops. Cover crops serve to naturally stem soil erosion while fixing nutrients into the soil and encouraging growth of various organisms. Crop yield is a major issue for farmers both in quality and quantity because the growing population of consumers regularly select and prefer purchasing higher quality crops over low quality ones. Therefore, farmers are now opting for modern farming methods, equipment and technologies to monitor their fields in real-time and improve quality food production. These modern farming methods, equipment and technologies employ artificial intelligence and big data, satellites, drones and robotic systems as well as Internet of Things (IoT), in a system collectively known as smart farming. These technologies usually have software segments or mobile applications which render the data obtained from sensors in formats which can be easily understood by the farmers. Therefore, smart farming utilizes various software and equipment to optimize and automate routine agricultural processes, thereby improving farmer productivity and crop production.

Table 1. Common cover crops and scientific names.

Class	Common name	Scientific name
Grasses	Ryegrass	*Lolium perenne*
	Rye	*Secale cereal*
	Wheat	*Triticum aestivum*
	Triticale	*Triticosecale*
	Oats	*Avena sativa*
	Barley	*Hordeum vulgare*
	Forage sorghum	*Sorghum biocolor*
	Millet	*Pennisetum glaucum*
Legumes	Soybean	*Glycine max*
	Cowpea	*Vigna unguiculata*
	Sunn hemp	*Crotalaria juncea*
	Alfalfa	*Medicago sativa*
	Clovers	*Trifolium* spp.
	Faba bean	*Vicia faba*
	Hairy vetch	*Vicia villosa*
	Lentil	*Lens culinaris*
	Medics	*Medicago* spp.
	Pea	*Pisum sativum*
	Serradella	*Ornithopus sativus*
Brassicas	Mustard	*Brassica nigra*
	Kale	*Brassica oleracea*
	Rapeseed	*Brassica napus*
	Radish	*Raphanus sativus*
	Turnips	*Brassica Rapa*
Non-legume broadleaves	Buckwheat	*Fagopyrum esculentum*
	Phacelia	*Phacelia tenacetifolia*
	Safflower	*Carthamus tinctorius*
	Sunflower	*Helianthus annuus*
	Spinach	*Spinacia oleracea*
	Flax	*Linum usitatissimum*

Artificial intelligence and big data

The field of artificial intelligence is concerned with developing systems that mimic human intelligence. Machine learning, a subset of artificial intelligence, refers to self-learning technologies that are concerned with predicting outcomes based on historical data. Machine learning together with big data obtained from sensors has been applied in agriculture for predicting soil and water parameters, climate change, rainfall patterns, fertilizer requirements, carbon content as well as the spread of pests and diseases. These help farmers make accurate forecasts, plan activities and make long-term as well as short-term decisions. Some researchers have described several contributions by artificial intelligence to improve agricultural productivity, grouping these contributions into general crop management, pest management, disease management, agricultural product monitoring and storage control, soil and irrigation management, weed management as well as yield prediction[27−29].

Satellites

Satellites can be used in smart farming for field analytics and tracking changes on farmlands based on high-resolution satellite images. This replaces the need for employing a large number of scouts to monitor the farm territory. With the aid of this technology, farmers can obtain regularly updated maps of their farms, monitor multiple farmlands remotely without the need to be on the field. Satellite technology also employs data mapping which uses accurate terrain data to aid farmers in speedily assessing the efficiency and quality of work performed on farmlands and plan further actions. Moreover, through their sensors, satellites can be used to apply spectral indices such as the Normalized Difference Vegetation Index (NDVI), Canopy Chlorophyll Content Index (CCCI), Normalized Difference RedEdge (NDRE) and Modified Soil-Adjusted Vegetation Index (MSAVI), amongst others. Spectral indices refer to scientific calculations applied to numerous spectral bands of a multispectral image, designed to highlight pixels showing the relative abundance or lack of a land-cover type of interest in the image[30]. The NDVI measures the density of vegetation in the field. Therefore, it is useful for the detection of vegetation content, the amount of wilting plants and overall plant health. Higher NDVI values could mean healthier vegetation. CCCI measures chlorophyll content in plants and provides farmers with crucial information about crop health and development, aiding in nutrient application and management throughout the growing season. NDRE measures Nitrogen and chlorophyll contents in plants and is useful for vegetation analysis in the mid-to-late growing seasons when the plants are quite mature and ready to be harvested. While, MSAVI aids in detecting uneven seed growth, thereby minimizing soil background impact during seed germination and leaf development stages. MSAVI can be used in place of NDVI and NDRE when they produce inaccurate data especially due to low vegetation or lack of chlorophyll in the plants, which occur during the early plant development stages when there is a lot of bare soil between seedlings.

Drones and robotic systems

Drones are useful for monitoring farms, aerial seeding as well as herbicides and pesticide delivery. Drones can also be used for aerial imagery and they provide better and more accurate data in higher resolution than satellites. Drones are helpful for application of herbicides and pesticides as they prevent farmers direct exposure to these chemicals which can lead to chemical poisoning. However, drone technology needs to be complemented with satellite technology as drones are inefficient for mapping or monitoring extremely large farmlands. Robotic systems usually have embedded sensors that help farmers to monitor changes within farms and the environment in real time. They can also be used to identify crop condition and selectively apply pesticides, manipulate farm products during harvesting as well as collect and convert useful information for the farmer. Some researchers have highlighted the usefulness of some agricultural robots in various stages of agricultural activities such as land preparation before planting, sowing/planting, plant treatment, harvesting as well as yield estimation and phenotyping[31,32].

Internet of Things (IoT)

IoT is a network of interrelated digital devices and machines which have embedded sensors for connecting and exchanging data with other devices over the internet[33]. Therefore, IoT relies on sensors which collect data from the farm, farming assets and crops, as well as the internet which aids in linking all available data sources into a single functional system. Sensors have been used in various areas of science and technology to obtain data and gain insight into the intricate workings of systems[34−38]. However, their implementation in agriculture as a whole, and cover crop farming in particular has numerous advantages, with the main advantage being that farm managers can know what is going on in their farms in real-time, even without being physically present. Other advantages include crop health analysis, smart pest and disease control, weather predictions and inventory analysis. Therefore, the sensors serve to extract and accumulate relevant information such as temperature, humidity and soil moisture content, which can be used to predict the state of the soil and improve crop yield. A number of researchers have presented the various technological aspects of applying IoT in agriculture[39,40].

Mechanized cover crop farming equipment

Several cover crop farming equipment and tools exist for making the cover crop farming process easier. In mechanized farming, these tools are usually attached to an airplane or a tractor and are used in turn to prepare the field for planting. The mechanized cover crop farming equipment can be grouped into preparation, planting, termination and incorporation equipment. The preparation equipment include the furrow chisel, undercutter and ring roller. The planting equipment include the aerial seeding or overseeding equipment, broadcasting-by-ground equipment and seed drill. The termination equipment include the roller-crimper and mower, while the incorporation equipment include the mechanical spader and tillage equipment.

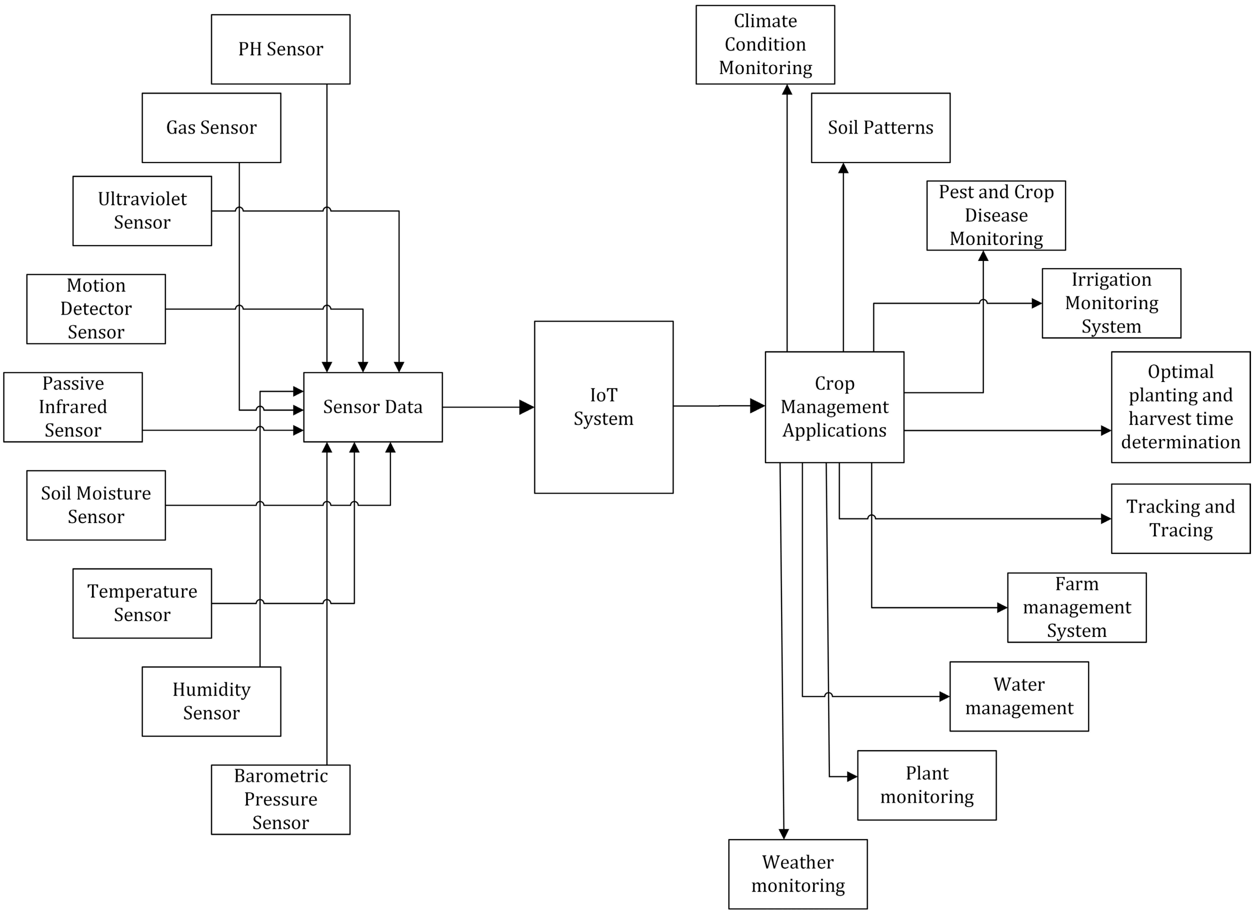

Fig. 2 Applications of sensors for crop management.

Preparation equipment

Before any farming operation is carried out on a farmland, it is best to prepare the farmland to ensure better yield from the farming operation. The mechanized cover crop farming preparation equipment are equipment that are used in preparing the soil for the cover crop farming operation. These equipment include the furrow chisel, undercutter and ring roller.

Furrow chisel

For preparing the farmland for planting cover crops, the furrow chisel or 3-bar cultivator is usually the first tool to use. In its simplest form, it is attached to a single bed which is in turn attached to a tractor. The main purpose of this tool is to break the soil compaction from the wheels of the tractor or compaction from previous cultivation on the field. Therefore, the furrow chisel serves to break up soil and increase infiltration, severe weed roots, stir and aerate the soil while preparing seed beds for planting season[41]. Apart from being cost effective and affordable, a desirable property of furrow chisels is the ability to withstand impact as well as abrasion resistance, so the tool can hold up in a variety of soil conditions.

Undercutter

The undercutter is usually the second tool used in the series of tools used for preparing the cover crop seed beds of a farmland. Undercutting is basically a process of drawing a blade under the soil, thereby slicing the plants underneath the soil. The undercutter is a very versatile, inexpensive and easy to build tool for eliminating potential weed growth especially for a farmland that has been left to fallow. Weed elimination is crucial as they compete for water, nutrients and light. The undercutter is usually attached to a tractor and is very effective at mechanically killing weeds and creating a thick, evenly distributed mulch while only slightly disturbing the seed bed. Therefore, the tool is useful when chemical weed control methods are highly undesirable. Studies have shown that the undercutter is most effective at killing plants at mid-to-late bloom and beyond[42].

Ring roller

The third tool that is usually used for preparing cover crop seed beds on a farmland is the ring roller. The ring roller is usually attached to a tractor and helps in smoothening the surface of the seed beds, thereby breaking down aggregated and compacted blocks of soil in the seed bed and eliminating large air spaces. Therefore, rollers are useful for crushing soil clods and compressing/firming the soil. Firming the soil has several advantages such as reduced soil moisture loss and easier weed control and harvesting as a result of the flatter land. Flatter land and well-leveled spreading of soil is important at planting because flatness is the only practical way to control the average depth of planted seeds without laborious hand planting of each seed.

Planting equipment

Planting or seeding is one of the most important operations and involves planting the cover crop seeds in the seed beds. There are various methods of applying cover crop seeds to the farmland. The method used affects seed germination rate and stand quality. These methods include aerial seeding or overseeding, broadcasting by ground, and seed drilling.

Aerial seeding or overseeding

In aerial seeding or broadcasting by air, a broadcast seeder attached to an airplane, helicopter or drone is used for spreading the cover crop seeds on the farmland. A high-clearance, ground-based equipment attached to a tractor can also be used to broadcast seeds. Airplanes are the most commonly used vehicle for aerial seeding mainly because they can carry large amounts of seeds and cover many acres of farmland quickly. However, the disadvantage of using airplanes is that they are imprecise, and must reload at airports, thereby increasing costs from fuelling. Helicopters are a better alternative to airplanes as they can cover large farmlands and helicopter landing can occur close to the farmlands for reloading thereby reducing fuel and time expenses. The disadvantage of the helicopter aerial seeding method is that the rotor blades of the helicopters can create turbulence which affects the evenness and predictability of seeding. Though drones can precisely place seeds on the farmland, they are more ideal for small, irregularly shaped fields with rough terrain. The limitation of using drones is that they can only carry small amounts of seeds at a time, and therefore cannot cover large areas quickly. Apart from being fast, easy and efficient at covering large areas in the least amount of time, the main advantage of aerial seeding or

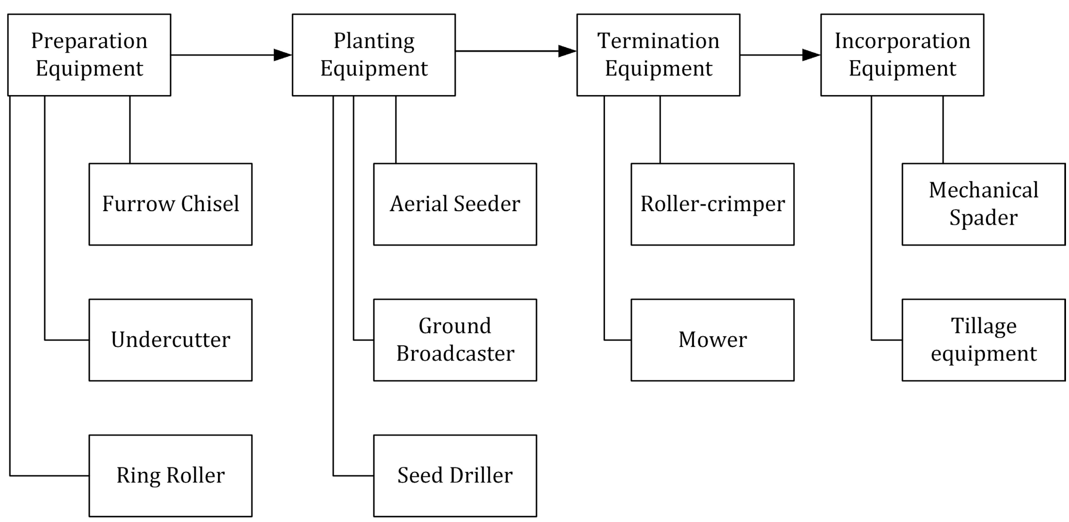

Fig. 3 Mechanized cover crop farming equipment.

overseeding is that it allows seeding of existing crops or seed application when the farmland is too wet for ground seeding. It is also suitable in situations where the cover crop has large seeds such as rye and wheat, but unsuitable for situations where the cover crop seeds are small such as small clover and grass seeds. Apart from being expensive, the disadvantage of this method is that it can result in slow germination of seeds and the need for a higher seeding rate.

Broadcasting by ground

This seeding method is very popular and accurate for introducing cover crop seeds to the seed bed. Broadcasting cover crop seeds by ground can be carried out with the aid of spinners or drop tubes attached to a tractor. Though this method is popular, farmers have to consider seed spread patterns because the seed spread patterns vary according to weights, with heavier seeds spreading further than lighter seeds. Therefore, farmers have to consider factors such as accurate seed metering before spreading and appropriate seeding pattern for complete and even ground cover. The InterSeeder is a modern multipurpose ground seed broadcasting machine that simultaneously plants rows of cover crops while spraying post-emergent herbicide and nitrogen fertilizer in single passes between several rows of crops[43].

Seed drilling

A typical seed drill usually consists of a beam to which a couple of tynes are fixed. The tynes create openings in the furrows into which seeds are dropped. Seed tubes are fitted to the tynes and connected to a seed receptacle known as a hopper. The main function of the seed tubes, which can be made of polypropylene, rubber or steel, is to carry seeds from the receptacle to the opened furrows. Therefore, a seed drill is an agricultural device for sowing cover crop seeds by positioning and burying them in the soil to a specific depth while being pulled by a tractor. The seed drilling method is advantageous because it ensures that cover crops seeds are planted at the appropriate seeding rate and depth, saving them from being eaten by birds and animals or being dried up by the sun. Therefore, the seed drill enables cover crop farmers to have precise control over the depth at which seeds are planted, thereby allowing seeds to take optimum advantage of available soil moisture and prevent early or late seed germination.

Termination equipment

Cover crops are usually terminated before planting the subsistence or cash crops, especially when that mode of cover crop planting is involved. Cover crops can be terminated by mechanical equipment, herbicides or natural causes such as exposure to winter conditions or selection of species that have a short lifecycle. Effectively terminating the cover crop is necessary because if not properly managed, the cover crops will compete with the subsistence or cash crops for moisture and nutrients. Several mechanical termination equipment exist to make the cover crop termination exercise easier. They include roller-crimpers and mowers

Roller-crimper

The roller-crimper is a mechanical means of terminating the cover crops on a farmland after they must have served their purpose. The roller crimper is usually attached to a tractor and basically consists of a round drum or cylinder with blunt curved blades mounted across the face of the drum. Though the roller-crimper serves the same purpose as a mower, unlike the mower, the roller-crimper lays the cover crop over in a particular direction and crushes its stems. This converts the cover crop into a dense mulch that can suppress weed growth on the farmland. Therefore, the rolling flattens the cover crop down to form a mulch layer while the crimping stops the flow of water from the roots to the shoots and the flow of sugars from the shoots to the roots by crimping their vascular system but not cutting the stems. Studies have indicated that roller-crimping has significantly high cover crop termination rates when compared to other non-rolled methods[44,45]. It has also been discovered that cover crops such as rye can be terminated effectively within weeks when rolling is delayed until the early kernel formation stage of reproductive growth[45]. Studies have also shown that roller-crimping operations may need the addition of herbicides such as paraquat and glyphosate for more effective cover crop termination[45,46].

Mower

Mowing is another mechanical means of terminating cover crops. The mowing method of cover crop termination relies on detaching the aboveground cover crop vegetation from the roots and mixing, chopping and shredding the residue on the soil surface. Various types of mowers exist for cover crop termination. Of these, flail mowers and rotary mowers are the most common. A flail mower utilizes flails attached to its rotating horizontal drum for cutting cover crops while the rotary mower uses rotating blades to cut the cover crop. Flail mowers are a better option than rotary mowers because they aid in chopping and distributing cover crop residue more evenly. On the other hand, the use of rotary mowers leaves large clumps of residue which may be difficult to incorporate into the soil. The advantage of mowing is the speed at which cover crops are terminated however mowing is energy intensive with the possibility for cover crop regrowth depending on species and time of termination.

Incorporation equipment

Incorporation is the process of introducing the terminated cover crop into the soil to decompose and serve as green manure. This has the advantage of improving soil health, but reduces the benefits of soil erosion prevention[47]. Incorporation can be carried out immediately or within a couple of days after termination to begin the decomposition process before planting the subsistence or cash crop. Cover crop incorporation equipment include mechanical spaders and tillage equipment.

Mechanical spader

The mechanical spader is used after termination of the cover crops on the farmland, to incorporate the cover crop residue into the soil. It is usually attached to a tractor and consists of a set of reciprocating mechanical spades, mounted on an eccentric or axle, that turn the soil over by digging, thereby incorporating the cover crop residue into the soil. The eccentric or axle of the spader is powered by the tractor's Power Take-Off shaft and the spades ensure that crop residue, fertilizer and green manures are mixed throughout the entire working depth of the farmland. The mechanical spading operation is usually carried out in multiple passes depending on the level of residue incorporation desired. The spader is useful because it incorporates residue for decomposition and breakdown, without destroying aggregation of the soil, thereby maintaining soil structure and preventing oxidation of soil organic matter.

Tillage equipment

Tillage refers to soil manipulation by mechanical means, in order to achieve desired soil conditions[48]. Soil can be tilled to modify its structure, kill weeds or incorporate crop residues. There are primary and secondary tillage equipment. Primary tillage equipment are those equipment used to work on soil to a depth of 15 cm to 90 cm[48]. They include moldboard, disk, rotary, chisel and subsoil plows. Secondary tillage equipment are those equipment usually used for seedbed improvement by increasing soil pulverization, stirring the soil at shallow depths after deeper primary tillage equipment operations as well as cutting up cover crop residues. Examples of secondary tillage equipment are cultivators, harrows, rollers, pulverizers as well as mulching and fallowing tools[48].

Conclusions

Cover crops are helping farmers increase crop yields, decrease environmental impacts of fertilizer use and improve soil health. The popularity of cover crops has given rise to the development of various methods, technologies and machinery options to plant and manage these crops. In this paper, several modern cover crop farming methods, equipment and technologies have been discussed. Firstly, the paper discusses the usefulness of the various classes of cover crops known as grasses, legumes, brassicas and non-legume broadleaves. These include nitrogen scavenging, nitrogen fixation, biomass production, weed and erosion control, nematode and pest control as well as soil structure improvement. The roles of some modern farming technologies in farming have also been discussed including artificial intelligence and big data, satellites, drones and robotic systems as well as Internet of Things (IoT). Clearly, these technologies are centrally based on sensors and the internet which connect them in a smart farming system. Finally, the paper describes some modern mechanized cover crop farming equipment, grouping them into preparation, planting, termination and incorporation equipment. These advanced equipment and technologies are aiding the cover crop farming process by making it safer, more efficient and environmentally friendly

Conflict of interest

The author declares that there is no conflict of interest.

Dates

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