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Weed Management Strategies for Conservation Agriculture and Environmental Sustainability in Nigeria

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Abstract: *With conservation agriculture (CA), crop production is not only primarily concerned with the production of food and industrial crops. Attention is geared towards crop production in an environmentally sustainable manner. Conservation agriculture which brings the environment to bear during crop production is challenged with weed problems that reduce agricultural productivity when not checked. Adoption of any compactible physical, biological or chemical weed management strategy to the existing cultural weed management of CA fulfils the multiple tactics of integrated weed management (IWM). IWM is beneficial to conservation agriculture; as it assists in the management of weed problems and non-availability of some weed control options. Thus, this review article discusses integrated weed management in relation to conservation agriculture and environmental sustainability.*

Keywords: *Integrated weed management, Conservation Agriculture, Environment*

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I. Introduction

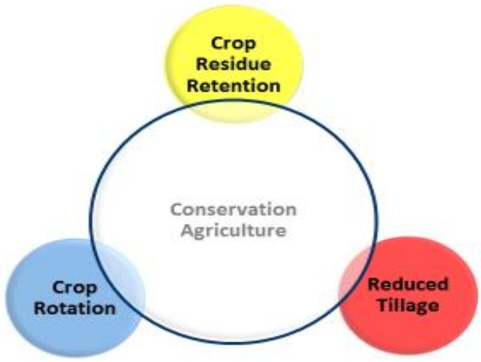
The decline in crop productivity due to the presence of weed has justified the need to manage weed infestation. Over the years, many weed control strategies have been employed. Tillage, whose main objective is to provide favourable soil condition for crops, functions as mechanical weed control technique since weeds are uprooted and buried into the soil in this land preparation practice (Wallace & Bellinder, 1992). More so, repeated tillage operations have been found useful in controlling perennial weeds due to its ability to reduce the energy reserve in perennial crops (Todd & Derksen, 1986) through the destruction of their storage organs and propagules. Tillage involves mechanical manipulation of the soil and plant residues (Hosseini *et al*., 2016). It is an integral part of conventional agricultural production (Farooq & Siddique, 2015). In addition to its weed control attribute, intensive tillage loosens the soil, improves the release of soil nutrients for crop growth, and modifies the circulation of water and air within the soil (Hosseini *et al*., 2016). Tillage affects soil properties such as temperature, moisture content, bulk density, porosity and infiltration which affect crops performance (Adebisi *et al*., 2016).

Conversely, tillage is also an agent of land degradation. Intensive tillage may worsen the soil through carbon loss and erosion resulting from excessive break down of soil aggregates (Reicosky, 2003). Tillage modifies the water holding capacity of the soil and causes drought in none or less plastic soils (Singh *et al*., 2016). The frequent use of heavy machinery for tillage releases greenhouse gas to environment and sometimes compact the soil. Sequel to the linked environmental problems of conventional tillage, conservation agriculture which emphasizes minimal disturbance of the soil among other components has become a trending practice in some countries. In the 21st century, conservation agriculture is practiced on 154 million hectares (Singh *et al*., 2015), with annual expansion of about 7 million hectares (Friedrich *et al*., 2012).

Conservation agriculture (CA) is an eco-friendly approach of farming that emphasizes minimal soil disturbance, diversified crop rotations, and surface crop residue retention (Farooq & Siddique, 2015; Fig. 1). The objectives of conservation agriculture are to preserve, mend and make judicious use of natural resources through unified management of available soil, water and other biotic constituents (Reicosky, 2003). No-tillage aimed at circumventing erosion has been practised in some countries without the incorporation of organic mulch. This cannot be regarded as a correct way of practicing CA (Friedrich *et al*., 2012). CA is a sustainable approach that prevents soil degradation and controls erosion. However, the isolated adoption of its components (reduced tillage, plant residue mulching, cover cropping and crop rotation) is common in Nigeria. Studies have revealed that CA has more benefits than the discrete adoption of its components (Nawaz *et al*., 2017; Rusinamhodzi *et al*., 2011; Lal, 1976), hence there is a need for advocacy on the unification of these components in Nigeria. The first record of conservation agriculture in Nigeria is traced to 1970 where Lal (1976) conducted research to study no-tillage and conventional method of tractor ploughing which significantly affected the physical and chemical properties of western Nigeria soil. No-tillage systems turned out to have some advantages over conventional tillage methods in attenuating water runoff and soil erosion. However, persistent practice of no-tillage with crops that leave no substantial amount of residue on the soil surface may seriously deteriorate soil physical properties. Hence, crop rotation that permits the combination of crops with inadequate residue with those with adequate residue solves this problem (Lal, 1976).

Weed control is the most difficult management issue in CA, since some control options such as bush burning and 'unrestricted' tillage are not possible options. Therefore, it was advocated that integrated weed management (IWM) be incorporated as a fourth component of CA (Farooq *et al*., 2011). Aside from weed problems in CA that is unique, CA mitigates many problems of the conventional agriculture. Soil erosion, soil compaction and water losses from runoff are lessened by reduced soil disturbance and maintenance of permanent soil cover (Serraj & Siddique, 2012). The plant residue component of CA and the incorporation of legumes in the crop rotation component help to improve the soil organic matter and the soil fertility (Marongwe *et al*., 2011). Consequently, CA increases biodiversity in agro-ecosystems (Landers *et al*., 2013). Also, the reduced usage of tillage machinery lowers carbon dioxides emissions and the resultant global warming (Govaerts *et al*., 2009).

FIGURE 1



Interception of the ring by the three components brings about CA

Weed Challenges in Conservation Agriculture

Weed interference is influenced more by the components of CA compared to conventional agriculture (Singh *et al*., 2015) that is characterised by intensive tillage, monoculture, clean cultivation (removal and burning of residue), and indiscriminate use of pesticides and fertilizer (Sharma & Singh, 2014). The crop residue component of CA maintains cool soil temperature and moist, thereby improving biodiversity, contrary to what is obtainable in conventional agriculture. No-till increased the number of annual weeds as a result of the accumulation of weed seeds on the soil surface (Nalewaja, 2003). Against the expected mortality of weed seeds on the soil surface due to weather variability and predation (Nichols *et al*., 2015), seed self-burial when the soil expands confers protection (Nalewaja, 2003). Also, reduced tillage alters weed species distribution, densities and composition (Bajwa, 2014). Overtime, emergence of more perennial weed species (weed flora shift) in reduced or no-till systems is rampant due to the minimal disturbance of the soil.

Environmental Degradation and Conservation Agriculture in Nigeria

Human-induced soil degradation is a common phenomenon in Nigeria. The extent of degradation varies from light for 37.5% of the area (342,917 km^2), moderate for 4.3% (39,440 km^2), high for 26.3% (240,495 km^2), to very high for 27.9% (255,167 km^2) (FAO, 2015). Concern over damage to soil structure resulting from various conventional tillage operations has led to interests in conservation tillage techniques such as minimum tillage, mulch tillage, and no-tillage (Akobundu & Deutsch, 1983) which differs from conventional tillage (traditional tillage) with respect to associated benefits (Hobbs *et al*., 2008; Table 1).

Soil erosion is the most common form of soil degradation in Nigeria. In 1989, the impact of runoff induced erosion was noticeable in about 75% of southern Nigeria. Gully and rill erosion are prevalent in the eastern Nigeria and along the rivers in northern Nigeria (Junge *et al*., 2010). Among other factors, soil type, watershed configuration, clearing of forest, intense rainstorms and increased intensity of cultivation led to erosion problems in Nigeria (Nwakor *et al*., 2015). If tillage is intensively performed or mechanised, it causes rapid degradation of soil physical, chemical and biological qualities especially in humid zones of southern Nigeria (Adebisi *et al*., 2016). Hence, this justifies the need for no-tillage adoption. Converse to chemical no-tillage practice, smallholder farmers in Nigeria usually solve weed problems of pre-plant fallow vegetation by slash-and-burn technique; dibble their crop seeds into the soil without tillage. Though no-till practice is involved, this negates the crop residue retention advocacy of CA.

The effects of erosion on agriculture and the environment rationalize its control. Erosion reduces soil fertility and productivity, decline crop yields, cause loss of vast agricultural land and poor water quality (Stacey, 2011). In Nigeria, erosion control is challenged by the prohibitive cost and unavailability of appropriate herbicide types that put a major constraint on the adoption of the no-tillage technique of erosion control (Oshunsanya *et al*., 2014). However, retention of plant residue and cover cropping that have physical and vegetative erosion control functions (Oshunsanya *et al.,* 2014) can be adopted and sustained with crop rotation. In the tropics, crop residue levels differ with abundance deposit in the humid tropics and near absence in parts of the savannah and most of the semi-arid tropics. Among other factors, excessive grazing, forest fire, sparse vegetation, and limited moisture account for the scarcity of crop residue mulch in the savannah and semi-arid regions (Akobundu & Deutsch, 1983).

Table 1: A comparison of tillage, conservation tillage (CT) and conservation agriculture (CA) for various issues.

issues	traditional tillage (TT)	conservation tillage (CT)	conservation agriculture (CA)
practice	disturbs the soil and leaves a bare surface	reduces the soil disturbance in TT and keeps the soil covered	minimal soil disturbance and soil surface permanently covered
erosion	wind and soil erosion: maximum	wind and soil erosion: reduced significantly	wind and soil erosion: the least of the three
soil physical health	the lowest of the three	significantly improved	the best practice of the three
compaction	used to reduce compaction and can also induce it by destroying biological pores	reduced tillage is used to reduce compaction	compaction can be a problem but use of mulch and promotion of biological tillage helps reduce this problem
soil biological health	the lowest of the three owing to frequent disturbance	moderately better soil biological health	more diverse and healthy biological properties and populations
water infiltration	lowest after soil pores clogged	good water infiltration	best water infiltration
soil organic matter	oxidizes soil organic matter and causes its loss	soil organic build-up possible in the surface layers	soil organic build-up in the surface layers even better than CT
weeds	controls weeds and also causes more weed seeds to germinate	reduced tillage controls weeds and also exposes other weed seeds for germination	weeds are a problem especially in the early stages of adoption, but problems are reduced with time and residues can help suppress weed growth
soil temperature	surface soil temperature: more variable	surface soil temperature: intermediate in variability	surface soil temperature: moderated the most
diesel use and costs	diesel use: high	diesel use: intermediate	diesel use: much reduced
production costs	highest costs	intermediate costs	lowest costs
timeliness	operations can be delayed	intermediate timeliness of operations	timeliness of operations more optimal
yield	can be lower where planting delayed	yields same as TT	yields same as TT but can be higher if planting done more timely

Source: Hobbs *et al.,* 2008

In Nigeria, between 2009 - 2014, an estimated average of 62.63×10^6 tonnes of crops residues were generated from cassava, cowpea, groundnut, maize, oil palm, plantain and sorghum (Table 2). Usually, crop residues from previous cropping season are used as mulch in the next cropping season. From these crops, less than 2.5 tonnes per hectare of crop residues are available to the land area used for arable crop production between 2010 and 2014 in Nigeria (Tables 3 & 4). Hence, when greater quantity of crop residue is desired, adoption of crop rotation that incorporates crops with more residues is an option where possible. In addition, crop rotation helps to prevent the build-up of pathogen and pest that could emanate from crop residues.

Integrated Weed Management

Integrated weed management is a sustainable practice that boosts agricultural productivity with an environmental conscious approach. Weed management is a sustainable practice that boosts agricultural productivity with an environmental conscious approach. Weed management aims at maintaining weeds with considerations such as thresholds and critical periods (Harker & O'Donovan, 2013). According to Akobundu (1992), 'weed-free crop fields may be aesthetically desirable, but they predispose the soil to erosion, especially before the crop develops full canopy cover'. Therefore, weed control that attempts to create weed-free situation is not environmental friendly. Integrated Weed Management (IWM) is part of integrated pest management (IPM) that is based on multiple control tactics and integration of pest biology knowledge for the management of the pest

(Buhler, 2002). IWM is 'the utilization of available weeds science knowledge to manage weeds so that they do not cause economic loss nor adversely affect the environment' (Akobundu, 1992). Thill *et al.*, (1991) defined IWM explicitly as 'the integration of effective, environmentally safe, and socially acceptable control tactics that reduce weed interference below the economic injury level'. It can be deduced from these definitions that IWM places emphasis on multiple tactics, economic consideration, and environmental safety. Eradication of weeds is not the focus of IWM but the reduction of weeds' competitive advantage below economic threshold (Buhler, 2006). IWM therefore balances between weed control and safety of the environment.

Table 2: Estimates of Crop Residue Production in Nigeria

	Residues (10^6 t)					
	2009	2010	2011	2012	2013	2014
Cassava Stalks	2.28	2.64	2.86	3.16	2.94	3.40
Cassava Peelings	9.21	10.63	11.55	12.74	11.85	13.71
Cowpea Shells	4.15	5.89	2.88	9.01	8.10	3.74
Groundnut Husks/shells	1.42	1.81	1.41	1.58	1.18	1.63
Groundnut Straw	6.85	8.74	6.81	7.62	5.69	7.85
Maize Cob	2.01	2.10	2.42	2.37	2.30	2.95
Maize Stalk	14.72	15.35	17.76	17.39	16.85	21.58
Maize Husk	1.47	1.54	1.78	1.74	1.68	2.16
Millet Stalks	8.63	9.05	2.22	2.24	1.59	2.42
Oil palm Shell	0.08	0.06	0.06	0.06	0.06	0.06
Oil palm Fibre	0.17	0.14	0.13	0.13	0.12	0.13
Oil palm Empty bunches	0.28	0.22	0.21	0.22	0.20	0.21
Palm Kernels Shells	0.10	0.10	0.09	0.10	0.10	0.11
Palm Kernel Cake	0.06	0.06	0.05	0.06	0.06	0.06
Plantains Peels	1.08	1.07	1.08	1.19	1.19	1.22
Plantains Trunks/leaves	1.35	1.34	1.35	1.49	1.49	1.52
Sorghum Straw	9.24	12.50	9.96	10.21	9.28	11.80
Total	63.09	73.24	62.63	71.30	64.69	74.53

Source: Product of Crop Production data from FAO statistics (http://www.fao.org) and Residue to Product Ratio (Jekayinfa & Scholz, 2009)

Table 3: Nigeria Land Area Used for Arable Production

	Year					
	2009	2010	2011	2012	2013	2014
Land Area(Sq. Km)	320000	330000	340000	350000	340000	340000

Source: World Bank Group, 2016 (http://data.worldbank.org)

Table 4: Residue Per Land Area Used for Arable Production

	Year					
	2009	2010	2011	2012	2013	2014
Tonnes/ Sq. Km	-	215	179	210	190	190

Based on multiple weed control strategies and reduced reliance on herbicides, there are intimations that IWM excludes the application of herbicides. IWM does not side-step any strategy to another. It rather sways the prudent utilization of all weed control systems (Harker & O'Donovan, 2013). Integrated weed management enhances the declining weed control efficacy that the use of single control method portends. The continuous use of any successful pest management practice without appropriate incorporation or rotation of other tactics, results in reduced control efficiency over time (Monaco *et al*., 2002). For instance, crop mimics are mistakenly omitted by hand-weeding in rice (*Oryza sativa* L.). The persistent use of hand weeding in rice allowed rice-mimic biotypes to escape weed management (Harker & O'Donovan, 2013). Also, sole dependence on herbicide for weed control results in herbicide resistance, weed flora shift, soil and environmental pollution (Chhokar *et al*., 2014). Integrated weed management is appropriate for some weed infestation situations that a single weed management method cannot control efficiently. Parasitic weeds can be successfully managed through the combination of cultural weed control (by rotating the host crop) and biological weed control (with trap crops) (Singh *et al*., 2015). Aladesanwa & Ayodele (2011), reported that paraquat and glyphoshate applied alone and in mixture in jute plots require supplimentary hand weeding to enhance weed control and promote jute production. This butresses the need for IWM and supports that integrated herbicide management that involves the use of multiple herbicides either sequentially or in mixtures does not sum up to IWM, since it has only the chemical control component. The multiple tactics of IWM need to be further clarified. It has been addressed as multiple direct control strategies by some weed scientists with less emphasis on preventive weed management (Chhokar *et al*., 2014; Robinson, 2014); whereas some perceived preventive weed management as an integral part IWM (Harker & O'Donovan, 2013; Knezevic, 2014). The underemphasised distinction between preventive weed control and preventive weed management could be responsible for this variance. Preventive weed control deters the establishment of weeds in the next cropping season (Bàrber, 2003). It is applicable when weeds or its propagative parts is already present and being debarred from growing or getting to the next cropping season whereas, preventive weed management methods prevent weeds from moving into a new environment (Zimdahl, 2007). The multiple weed management tactics of IWM is best as multiple weed control strategies in addition to preventive weed management that should be a permanent component (Figure 2).

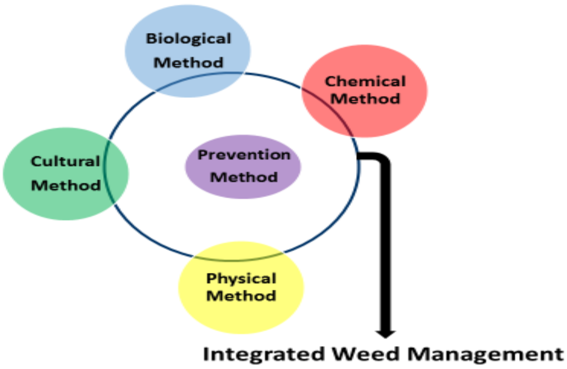


Figure 2: *Interception of the ring by more than a method brings about IWM

Generally, weed management tactics are of five methods namely; i.) Preventive method ii.) Physical method iii.) Biological method iv.) Chemical method and v.) Cultural method (Labrada & Parker, 1994). These methods can be classified into indirect (preventive) control and direct (cultural and curative) control, with the former done prior to planting and the latter done within the growing cycle of crops (Bàrber, 2003). IWM is a method of methods and these methods are discussed below:

Preventive weed management method

Prevention method encompasses all measures that curb the introduction and spread of weeds (Rao, 2000). The use of crop seeds and equipment that are free from weed seeds, isolation of imported animals, scouting for new weeds and deterrence of the seed production by weeds on the field are examples of preventive measures (Monaco *et al*., 2002). These measures are indirect methods of weed control whose objective is mainly to reduce the numbers of other plants emerging with a crop (Bàrber, 2003). Prevention focuses on potential problem that is not in existence. Hence, the results of preventive efforts are difficult to assess (Zimdahl, 2007).

Physical weed control method

Physical weed control involves the use of force, heat or some other physical forms of energy to break, cut off, destroy, burn or severely injure weeds (Swarbrick & Mercado, 1987). Manual weeding, mechanical weeding, and thermal weeding are examples of physical weed control. Manual weeding involves hand weeding and the use of simple hand tools. Mechanical weed control involves the cutting, uprooting, and burying of weeds (Riemens, 2016) through the use of machinery (Ehi-Eromosele *et al*., 2013).

Chemical weed control method

Chemical weed control involves the use of synthetic herbicides to kill or adversely affect the growth of weeds. Herbicide could be foliar applied or soil applied. Base on the time of application, herbicides are classified into pre-emergence and post-emergence herbicides; and base on herbicide movement in plants, there are systemic and non-systemic (contact) herbicides. Selectivity of herbicides determines their compatibility with crop and the type of weed they control. The use of herbicides is an effective means of controlling weeds. However, this is associated with concerns such as weed flora shift, weed resistance, and environmental pollution. In Nigeria, various herbicides are registered for use (Table 5). However, the adoption of chemical weed control is challenged by availability of herbicide (Ogungbile & Lagoke, 1986), cost of herbicides (Kughur, 2012), adulteration of herbicides and farmers' inability to read label instructions.

Biological weed control method

Biological weed control involves the use of other living things in controlling weeds. It encompasses the use of organisms and biologically based products (Ehi-Eromosele *et al*., 2013). Bio-herbicides are phytopathogenic microorganisms or microbial phytotoxins use for biological weed control, applied in similar ways to conventional herbicides (Boyetchko & Peng, 2004). Other commonly used biological weed control strategies are allelopathy, animal grazing, use of resistant or tolerant crop varieties and use of phytophagous insect.

Cultural weed control method

Cultural weed control involves the manipulation of farm practices to the advantage of crop growth at the expense of weeds. Basically, cultural weed control involves the use of farm practices to suppress weed growth through the modification of the environment. Manipulation of sowing time, crop fertilization, and spatial arrangement are examples of cultural practices commonly used to enhance the competitive advantage of crops over weeds (Das, 2008).

Integrated Weed Management in Conservation Agriculture

Despite the benefits of CA, it has only been practised globally on about 9 percent of the total cropped area (Friedrich *et al*., 2012). Weed management is one of the impediments affecting its adoption globally. The benefits that IWM portends necessitate that its adoption in CA be reviewed. Irrespective of farming system, IWM is constant in approach with multiple tactics, economic and environmental considerations constituting its fundamentals. However, IWM differs in CA from when practised in conventional agriculture base on the limited available weed control options. Keeping tabs on environmental safety is the main objective of IWM and CA. Weed control strategies in CA are restricted to those that align with the components of CA. For instance, tillage is not an option for weed control in CA (Nichols *et al*., 2015), likewise bush burning that does not allow for retention of crop residue.

Table 5: List of Herbicides Registered for use in Nigeria by NAFDAC

Organophosphorus	Amideherbicides	Triazines and Triazoles	Chlorophenoxy Herbicides	Urea And Guadinidines	Quaternary Nitrogen	Other Herbicides	Carbamates
Piperophos	Acetochlor	Atrazine	Prometryn	Diuron	Paraquat	Dimethachlor	Asulam
Anilofos	Alachlor	Ametryn	Simazine	Linuron	Diquat	Metazachlor	
Glyphosate	Propanil	Desmetryn	2.4-D	Fluometurone		Monosodium Methyl Arsonate (MSMA)	
Glyphosate Trimesium	Butachlor	Terbuthalazine		Chloroxuron		Fluxixpyr	
	Metalochlor	Terbutrex Terbutryne		Neburon		Imazaquine	
						Triassulfuran (Amber)	
						Osethoxydim	
						Oxadiazon (Ronster)	
						Clomaone	
						Trifluralin	
						Pedimethalin (Stamp 500)	
						Fluazifop – P.butyl	

Source: Federal Ministry of Agriculture & Rural Development (2013)

The reduced weed control options in CA tend to increase reliance on herbicides with attendant weed resistance (Singh *et al*., 2015). The persistence of some herbicides affects the crop rotation component of CA especially when the herbicide is not selective to the next crop in rotation (Colquhoun, 2006). This gives rise to the challenge of compatibility amongst the weed control tactics, since the crop rotation components of CA is also a weed control strategy (Nichols *et al*., 2015). Crop rotation breaks the life cycle of weeds and crop–weed specificity (Rao, 2000), thereby reducing weed persistence and its attendant challenges. The crop residue retention of CA creates environmental sieve that inhibit weed seed germination either by preventing sunlight to the seeds and providing a physical barrier to impede their emergence (Bahadur *et al*., 2015) or through the exudation of allelopathic plant materials (Jabran, 2016). However, the effectiveness of pre-emergence herbicides on the soil surface is reduced due to interference of crop residues present (Hartzler & Owen, 1997). Also, crop residue could be source of weed seeds. However, the preventive weed management component of IWM could effectively put this to check.

II. Conclusion

Advocacy for measures such as CA that prevent human-induced soil degradation is justifiable. The adoption of CA attenuates erosion and some other associated challenges of tillage. However, emergence of unique weed challenges in CA requires that its inbuilt weed management component (cover crop, crop residue mulching and crop rotation) be complemented with other weed management strategies without compromising its principles. Adoption of any compatible physical, biological or chemical weed management strategy to the existing cultural weed management of CA fulfils the multiple tactics of IWM. The reduced weed management options in CA tend to increase reliance on herbicide which could cause water contamination, weed resistance, weed flora shift, and herbicide carryover. IWM checks overreliance on herbicide. Hence, embracing IWM in CA assists its sustainability and enhances the environment protection focus.

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