

Role of Agro-Chemicals in Agriculture for National Development for Food Security

¹Omar Abdullahi Wafudu Handy, ²Amina Ibrahim Omar and ³Mohammed Isa

¹Department of Science Laboratory Technology, Federal Polytechnic Mubi, Adamawa State, Nigeria.

^{2,3}Department of Horticultural Laboratory Technology, Federal Polytechnic Mubi, Adamawa State-Nigeria.

Corresponding author: abdulwafud@gmail.com

Abstract

Chemistry has been, and for the foreseeable future will remain, extremely important for crop protection. Control of fungal pathogens, insect pests and weeds is crucial to enhanced food provision. Agrochemicals, as the name suggests, are used in agriculture to facilitate plant growth and protection as well encouraging more people to become farmers. As world population continues to grow, it is timely to assess the current situation, anticipate future challenges and consider how new chemistry may help meet those challenges. In future, agriculture will increasingly be expected to provide not only food and feed, but also crops for conversion into renewable fuels and chemical feed stocks. This will further increase the demand for higher crop yields per unit area, requiring chemicals used in crop production to be even more sophisticated. Chemistry forms an integral part of in agriculture often aims at preserving or increasing the fertility of soil, maintaining or improving the agricultural yield, and improving the quality of the crop. Chemistry deals with compounds, both organic and inorganic, and agriculture deals with the production of organic products using both organic and inorganic inputs. Thus, the aim of this study is to point out different chemicals used in today's farming system. To point out the importance of agro-chemical in modern farming, also, to encourage more people to go into agriculture.

Keywords: Agro-chemicals, Agriculture, Organic, Inorganic, Chemicals, Farming system.

Introduction

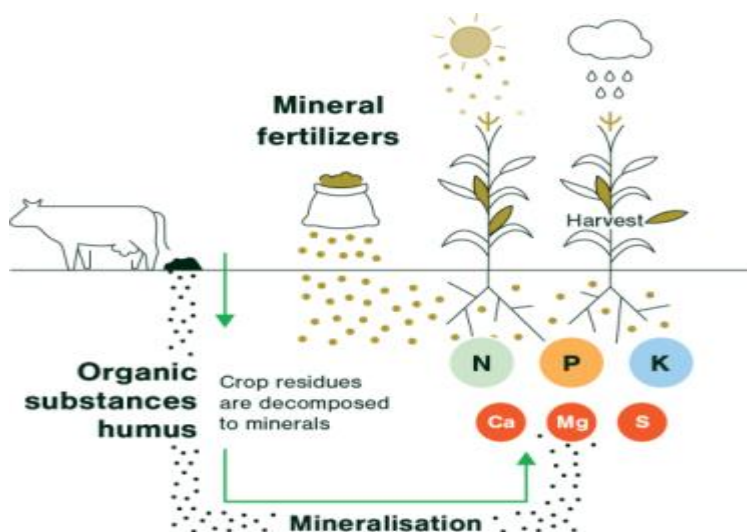
Chemistry has been the backbone of crop protection strategies for arable farming and food production. The control of weeds, fungal pathogens, and insect pests has made a vital contribution to food provision worldwide by ensuring the harvested yield of the world's crops. The basic need of human beings is food. Chemicals are added to promote the ripening of fruits or the germination of seed s(Ndaghu, Mukthar, and Michael 2018).. Food packaging has advanced due to the material produced by advancements in chemistry. Agricultural chemistry has increased the diversity of the human diet and has led to a greater overall availability of food, both animal and plant, (Vats, S 2015). It is agriculture only that fulfills this need for the entire population of the world. Plants are called producers as they synthesize their own food using CO₂ from air and water from soil utilizing sunlight as a source of energy by a process known as photosynthesis. The rest of the food chain consists of consumers only. The practice of producing crops and livestock from the natural resources

of the earth is called Agriculture. Modern agriculture includes agronomy, horticulture, animal husbandry, dairying, soil chemistry, etc.

Chemical materials developed to assist in the production of food, feed, and fiber include scores of herbicides, insecticides, fungicides, and other pesticides, plant growth regulators, fertilizers, and animal feed supplements. Chief among these groups from the commercial point of view are manufactured fertilizers. Therefore, farmers tend to apply soil amendments (synthetic or organic amendments) that are rich in nutrient, i.e., N, P, and K to enhance soil fertility and increase crop productivity. (Keteku et al. 2019) However, most growers apply fertilizers based on the general recommendations for each crop without prior knowledge of the soil fertility status and nutrient mineralization and release pattern from the fertilizers, synthetic pesticides (Pesticide Stewardship Briefing Document 2017), (Pinho 2014, 2021) and herbicides also, supplements for feeds. (Vats, S. 2015).

Objectives of the study

the aim of this study is to point out different chemicals used in today's farming system. To point out the importance and usage of agro-chemical in modern farming to farmers compared to traditional farming, also, to encourage more people on the role sustainable agriculture



Chemistry deals with compounds, both organic and inorganic, and agriculture deals with the production of organic products using both organic and inorganic inputs. Thus Chemistry forms an integral part of agriculture from molecular to organ level. It plays a role from the basics of photosynthesis to the utilization of agricultural produce. The advancements in this practice are only because of active research carried out in chemistry and then its applications to cause the land to produce more abundantly and at the same time to protect

it from deterioration and misuse. Without Role of Chemistry in agriculture can be classified as follows:

Photosynthesis: This natural process provides the basic building block for all agricultural products. The overall process is best shown by the net equation. $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$. No chemical process is more important to live on earth than photosynthesis not only would there be no plants, the planet could not sustain the life of any kind. Research in this area has led to understanding the mechanism and hence optimizing conditions for the maximization of this process.

Fertilizers: Are organic or inorganic material are chemical substances supplied to the crops to increase their productivity. These are used by the farmers daily to increase the crop yield. The fertilizers contain the essential nutrients required by the plants, including nitrogen, potassium, and phosphorus of natural or synthetic origin that is added to a soil to supply one or more plant nutrients essential to the growth of plants. There are different types of fertilizers such as, Ammonium nitrogen, Nitrate nitrogen, Amide nitrogen, Phosphorus, (Keteku et al. 2019) Mixing soluble phosphate, Citrate-soluble phosphates. Chemical fertilizers, such as urea, diammonium phosphate and single superphosphate (SSP), are used to maintain the shortage of nitrogen, phosphorus, and potassium in the soil. However, most of these fertilizers are lost as they flow or evaporate. Three main macronutrients: Nitrogen (N): leaf growth, Phosphorus (P): Development of roots, flowers, seeds, fruit; Potassium (K): Strong stem growth, movement of water in plants, promotion of flowering and fruiting.

Disadvantage of fertilizer

However, excessive use of chemical fertilizers has led to several issues such as serious soil degradation, nitrogen leaching, soil compaction, reduction in soil organic matter, and loss of soil carbon. Fertilization may affect the accumulation of heavy metals in soil and plant system cause soil pollution. Plants absorb the fertilizers through the soil; they can enter the food chain. Thus, fertilization leads to water, soil and air pollution. However, excessive use of chemical fertilizers has led to several issues such as serious soil degradation, nitrogen leaching, soil compaction, reduction in soil organic matter, and loss of soil carbon. Chemical fertilizer overuse can contribute to soil acidification and soil crust, thereby reducing the content of organic matter, humus content, beneficial species, stunting plant growth, altering the pH of the soil, growing pests, and even leading to the release of greenhouse gases.

Some examples of chemical fertilizers are ammonium-sulphate, ammonium-phosphate, ammonium nitrate, urea, ammonium-chloride and the like (Adebayo and James 2014). Agricultural waste Livestock manure. A recent assessment found that about 40 to 60% of crop yields are attributable to commercial fertilizer use. (Kahlau, Sabine; et al; 2020)



Fertilizers can be divided into two categories: organic and inorganic. Organic fertilizers are derived from living systems and include animal manure, fish and bone meal, and compost. These organic fertilizers are decomposed by microorganisms in the soil to release their nutrients for use by plants. Chemical fertilizers are less complex and have high concentrations of chemicals that may be in short supply in the soil namely nitrogen, phosphorous, potassium, calcium, magnesium, and sulfur. Fertilizers also provide micronutrients that are required in much smaller quantities namely boron, chloride, copper, iron, manganese, molybdenum, and zinc. (Keteku et al. 2019)

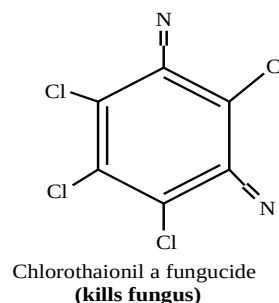
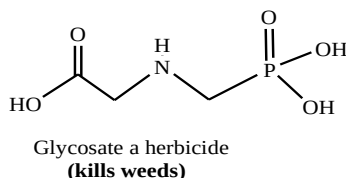
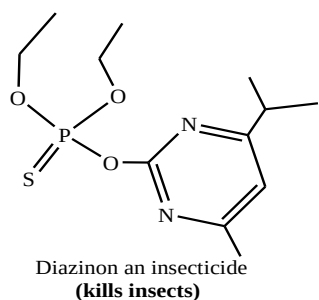
Inorganic fertilizer is synthesized using the Haber-Bosch process, which produces ammonia as the end product as shown $3\text{H}_2 + \text{N}_2 \rightarrow 2\text{NH}_3$. This ammonia is used for other nitrogen fertilizers, such as anhydrous ammonium nitrate and urea. Now fertilizers with a slow release of nutrients have been developed. Inorganic fertilizers are associated with reduction in some soil properties and crop yields over time, while application of organic fertilizer has positive effects in maintaining the soil properties. Appropriate use of fertilizers to increase crop yield has counterbalanced loss of land due to urbanization and significantly supported global population growth (Adebayo and James 2014) It has been estimated that almost half the people on the Earth are currently fed as a result of synthetic nitrogen fertilizer use.



Pesticides and Insecticides

In order to minimize the damage of the crops by pests, a large variety of chemicals known as pesticides are used. Subclasses of this are herbicides, insecticides, fungicides, rodenticides, pediculicides, and biocides depending on its target. With active research in this field safer and greener pesticides are being developed (Atwood and Paisley-Jones 2017) Insecticides are chemicals that are used to kill insects because they can spread livestock diseases, can eat stored grain, and can feed on growing crops. However not all insects are harmful, and certain species of insects are needed to pollinate plants to ensure that they set

seeds. These chemicals prevent crop losses to insects and other pests. One study found that not using pesticides reduced crop yields by about 10%. (Pinho, Bárbara 2021)



Chemistry in other areas of agriculture

Plastic pipes for improved irrigation: Plastic was derived from chemistry and is widely used in agriculture. This has increased irrigation massively which results in a better environment for the crops to prosper in. Protected cultivation films greenhouse and tunnel, Low tunnel, mulching, nursery, films, covering vineyards and orchards.

Nets (Ant-hail, Anti- birds, Wind breaking, Shading, Nets for olives and nut picking.

Packaging. Fertilizer sacks, Agrochemical cans.

Containers. Liquid tanks, Crates, Piping. Irrigation/drainage, Water reservoir, Channel lining, Irrigation tapes and pipes, Drainage pipes, Micro-irrigation, Drippers.

Others are, (silage, Fumigation films, Bale twines, Nursery Pots, Strings and ropes.

The world consumption of plastics in agriculture amounts yearly to 6.5 million tons. In addition to conventional polymers used in agriculture for greenhouses and mulches such as PE, PVC, EVA, photo-selective and luminescent polymers have been used, in order to improve the quality of crops. For the same reason plastic nets are used mainly in countries with tropical and Mediterranean climates. For an environmentally friendly agricultural activity, an alternative strategy can be represented by bio-based agricultural raw materials. For low environmental impact applications, biodegradable materials for agricultural films are nowadays produced. An overview of the main methods for the disposal and recycling of plastic materials are presented with the results of mechanical and radiometric tests on recycled plastics. The strategies to reduce the burden of plastics in agriculture are: a correct procedure for the collection, disposal and recycling of post-consumption plastics; the increase of lifetime duration and performance; and the introduction and promotion of bio-based materials.

Chemicals used in storage and preservation of agricultural produce:

Sulfur dioxide is used to keep grain fresh and useable for a longer period of time. Food preservatives like sodium benzoate and salicylic acid are used for longer shelf life. New generation refrigerants have been developed. Chemicals are added to promote the ripening of fruits or the germination of seeds. Food packaging has advanced due to the material

produced by advancements in chemistry. Agricultural chemistry has increased the diversity of the human diet and has led to the greater overall availability of food, both animal and plant.

Food Processing:

- i. Development of Saccharin and sweeteners, Vitamins, and minerals. Consumers have benefited from new technologies that have enhanced the flavor, appearance, availability, and nutritional value of their food.

Chemicals from agricultural waste:

- ii. Advancement in Chemistry has resulted in the development of technologies to produce a variety of chemicals from agricultural waste. Production of alcohol from bagasse which is used as the feedstock for chemicals is a good example. What products can be made from agricultural waste?

Uses for Agricultural Waste

Biofuels. Plant waste can produce biofuels such as biodiesel or ethanol. ...

Plastic substitutes. After the juice has been extracted from sugarcane, the stalk that is left is known as bagasse. Bioplastics. Bioplastics are getting both stronger and greener. Compost Agricultural wastes include crop residues, weeds, leaf litter, sawdust, forest waste, and livestock waste.

An herbicide is a chemical compound (pesticide) used to kill unwanted plants. Selective herbicides kill certain targets while leaving the desired crop relatively unharmed. Some of these acts by interfering with the growth of the weed and are often based on plant hormones. (*Forouzesh, et al 2015*) Herbicides used to clear waste ground are nonselective and kill all plant material with which they come into contact. Some plants produce natural herbicides, such as the genus *Juglans* - walnuts. Herbicides are widely used in agriculture and in landscape turf management. They are applied in total vegetation control programs for maintenance of highways and railroads. Smaller quantities are used in forestry, pasture systems, and management of areas set aside as wildlife habitat. Herbicides have been alleged to cause a variety of health effects ranging from skin rashes to death. The pathway of attack can arise from improper application resulting in direct contact with field workers, inhalation of aerial sprays, food consumption and from contact with residual soil contamination (*Augustine A N et al; 2018*).

Herbicides are used in agricultural and wild land ecosystems to reduce the density of weeds and promote the growth of desirable species. Use of herbicides in agro ecosystems may change composition of weed populations. In wild lands, herbicides may increase the diversity of native species. Herbicides are of different types such as broad spectrum these work on a wide variety of weeds. Selective - these work on a narrow range of weeds. Contact - these destroy plant tissue at or near the point of contact (they do not spread around the

plant), and require even coverage in their application. Broad Spectrum Non-Selective / Non-Residual Herbicide

The broad-spectrum herbicide glyphosate (common trade name "Roundup") was first sold to farmers in 1974. Since the late 1970s, the volume of glyphosate-based herbicides (GBHs) applied has increased approximately 100-fold. (Talbot, AR et al; 1991).

Broad Spectrum Herbicide is a non-selective, weed control for grasses and broadleaf weeds. It is formulated to deliver maximum performance and provide fast-acting results on a long list of weeds and grasses, as well as most mosses and lichens. Glyphosate - known by many trade names, including Roundup—has been the most widely used herbicide in the United States since 2001. Crop producers can spray entire fields planted with genetically engineered, glyphosate-tolerant seed varieties, killing the weeds but not the crops.

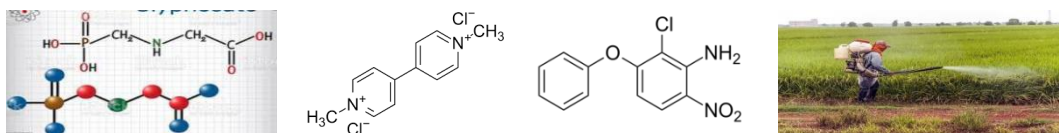


Figure: Roundup Paraquat Gramoxone Aclonifen herbicide

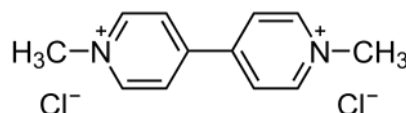
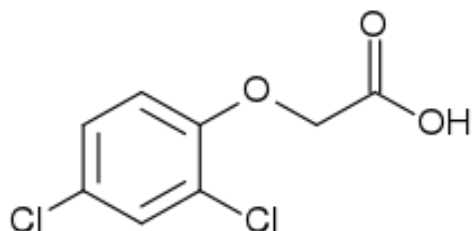
Roundup. Its herbicidal effectiveness was discovered by Monsanto chemist (John E. Franz 1970 (Monsanto 1974) brought it to market for agricultural use in 1974 under the trade name Roundup.

2,4-D is a widely used herbicide that controls broadleaf weeds that has been used as a pesticide since the 1940s. It is used in many places including turf, lawns, rights-of-way, aquatic sites, forestry sites and a variety of field, fruit and vegetable crops. It may also be used to regulate the growth of citrus plants, (King, Jessica 2012)

Structure of Herbicide: The most important chemical groups of herbicides are chlorophenoxy acids such as 2, 4-D and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), triazines such as atrazine, hexazinone, and simazine; organic phosphorus chemicals such as glyphosate; amides such as alachlor and metolachlor; thiocarbamates such as butylate.

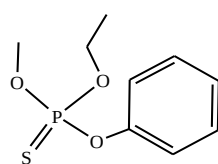
Paraquat is a toxic chemical that is widely used as an herbicide plant killer, primarily for weed and grass control. In the United States, paraquat is available primarily as a liquid in various strengths. Paraquat was first described by (Smith, 1995) discovered its redox properties and called the compound methyl viologen. The herbicidal properties of paraquat were first described by and it became commercially available in 1962. Paraquat is commonly sold under the trade name Gramoxone, but the herbicide is also sold under many different names, such as: Parazone. Para-Shot 3.0 Paraquat -N,N'-dimethyl-4,4'-bipyridinium dichloride, also known as methyl viologen, is an organic compound with the chemical formula $[(\text{C}_6\text{H}_7\text{N})_2]\text{Cl}_2$. It is classified as a viologen, a family of redox-active heterocycles of similar structure (Keteku et al. 2019). This salt is one of the most widely used herbicides. It is quick-acting and non-selective, killing green plant tissue on contact. It is also toxic (lethal) to human beings and animals due to its redox activity, which

produces [superoxide](#) anions. It has been linked to the development of [Parkinson's disease](#) and is banned in several countries. Paraquat may be in the form of [salt](#) with [chloride](#) or other anions; quantities of the substance are sometimes expressed by cation mass alone.

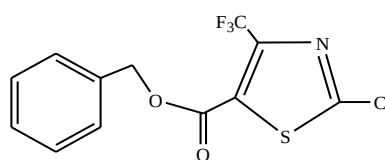


Aclonifen is a diphenyl ether herbicide which has been used in agriculture since the 1980s. The nitrophenyl ethers are a well-known class of herbicides, the oldest member of which was nitrofen, invented by Rohm & Haas and first registered for sale in 1964. This area of chemistry became very competitive, with the Mobil Oil Corporation's filing in 1969 and grant in 1974 of a patent to the structural analog with a COOCH_3 group adjacent to the nitro group of nitrofen. This product, bifenox, was launched in 1981. Meanwhile, introduced acifluorfen as its sodium salt. It had much improved properties including a wider spectrum of herbicidal effect and good safety to soybean crops.

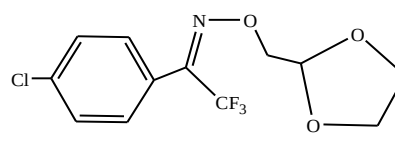
Atrazine is a chlorinated triazine systemic herbicide that is used to selectively control annual grasses and broadleaf weeds before they emerge. Pesticide products containing atrazine are registered for use on several agricultural crops, with the highest use on field corn, sweet corn, sorghum, and sugarcane (Cerde 2021).



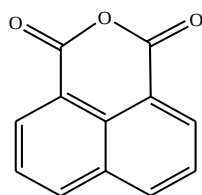
Dietholalate
(Rice and Cotton)



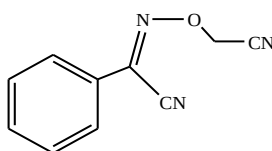
Flurazole (MON4606)
Sorghum



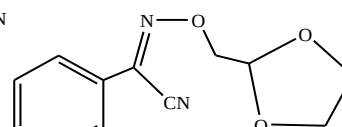
Flurofenim (CGA133205)
Superseded Oxabtrinil Sorghum



Benzo[de]isochromene-1,3-dione
Naphthalic anhydride CORN



Cyometrinil (CGA 43039)
Sorghum



Oxabtrinil (CGA92194)
Superseded Cyometrinil Sorghum

One of the main causes of food insufficiency in Africa particularly in Nigeria is the high prevalence of storage pests. Grains, dry legume seeds and tubers are excellent food not only to humans but also to lots of other creatures. Food stores are excellent breeding sites for all those pests. A farmer has to take adequate measures about food storage to conserve his/her crops to be able to feed the family even during longer droughts. The main storage

pests, apart from rodents, are beetles and moths. Some pests such as grain borers, weevils and Angoumois grain moths are able to feed on whole, healthy grains, they are considered primary pests. Secondary pests such as flour beetles can attack only broken grain, moist and thus soft grain, grain damaged by primary pests or processed products such as flour. Contamination by fungi, also causes direct loss and pose a threat to human and animal health by producing poisons known as mycotoxins, which contaminate food and feed. The main beetle pests of storage are bruchids (e.g. cowpea seed beetles and bean bruchid), grain borers (e.g. the larger and the lesser grain borers), weevils (e.g. grain weevils), flour beetles, Khapra beetles and dried fruit beetles (FAO 2019). The larvae and some adult beetles feed in the seeds and grain, leaving them full of small holes. Sometimes a fine dust is found around the holes, being the excrements of these beetles. Beetle damage renders grains and seeds unsuitable for human and in case of heavy attack even for animal consumption. (Ndaghu, Mukthar, and Michael 2018)

Mechanized farming use of chemical and fertilizers by Margi tribe in Madagali of Adamawa State-Nigeria.



Modern farming use of agro-chemicals by Margi tribe in Madagali of Adamawa State-Nigeria



Traditional farming of Margi tribe in Madagali LGA. Maize destroyed by insect (Ndaghu and Michael 2018)



Rodent and insect destruction in Adamawa State (Ndaghu, Mukthar, and Michael 2018)

In all these Chemistry is being playing role through application of fertilizers herbicides, pesticide, rodenticides, insecticides, fungicides. A new hybrid of maize was investigated under four treatments; No fertilizer, organic fertilizer, organic + Inorganicfertilizer and Inorganic fertilizer (NPK) The treatments were arranged in randomized complete block

design (RCBD) with 4 replications. Fertilizer application rate was 300 kg/ha. The results have demonstrated that the organic + inorganic fertilizers and inorganic fertilizers produced the greatest yield, which is then is recommend for maize production(Liu et al. 2017) (Keteku et al. 2019)

Table1. Farming system in Madagali Local Government Area of Adamawa State – Nigeria

Description	Plant height 8WAP	leave A 8WAP	yield p/ha	Cob yield tones/ha
No fertilizer	226b	272b	3.9b	2.0c
Organic fertilizer	226b	326b	4.0b	2.1b
Org + Inorg fertilizer	232a	288a	7.3a	2.3a
Inorganic fertilizer	232a	282a	7.5a	2.4a

Values followed by same letter in a column are not significant different: $P \leq 0.05$ (Agegnehu et al. 2016)

From the table 1 demonstrated that the organic + inorganic fertilizers and inorganic fertilizers produced the greatest yield, which is then is recommend for maize production. Government has to ensure and make early procurement and distribution of chemicals, fertilizers and seeds to the farmers to increase yield (FAO 2019) (G.Y 2013), if they actually need to increase the World food produced from agriculture. Without this, I think without all these, the farmer will just be bogging himself throughout the farming season and there will a lot of unemployment and hunger(Keteku et al. 2019).

Conclusion

This study which has been successfully carried out, revealed the role of agro-chemicals to farmers in madagali local government area of Adamawa State, has provided new innovative ways to widen the boundaries of agriculture and combat potential problems and thus increase productivity and quality of produce more especially, maize sugum, rice, beans, potatoes.in the area. This of course has encourage more youth into farming system. (Agegnehu et al. 2016). Agro-chemicals have been effective in the development of pesticides that have reduced pesticide crop damage. Pesticides include fungicides, herbicides, biocides, and insecticides, depending on the pest. (FAO 2019). The application of these pesticides reduces the pests' impact on crops by 10%. Thus Chemistry has been and is still closely linked to the progress in the agriculture (Keteku et al. 2019). It provides innovative new ways to widen the boundaries of agriculture and combat potential problems and thus increase productivity and quality of produce (Smith, Evans, and El-Hiti 2008). As our motor reveals, what on earth is not chemistry? There is no endeavor of human activity on earth that you do not find chemistry. Food we eat, the water we drink, the air we breathe all is chemistry. All drugs are chemicals but not all chemicals are drugs. Access to information plays a very significant role in ensuring that farmers were able to adopt

improved technologies that will boost their production through agrochemicals. All these can be achieved with chemicals and fertilizers. Chemicals and Fertilizers are agrochemicals produced from chemistry products and other farm inputs. Recently, government has inaugurated a Presidential Committee on farm blending. Even with the role of Chemistry, if we do not have proper internal mechanism to ensure early procurement and distributions of such chemicals, fertilizers and seeds will be in the same position.

Recommendation

1. Government should make awareness to farmers on how to use chemicals and fertilizers.
2. Government has to ensure and make early procurement and distribution of chemicals, fertilizers and seeds to the farmers to increase yield, if they actually need to increase the World food produced from agriculture.

References

- Adebayo Abayomi, Olowoake, and Ojo James Adebayo. 2014. "Effect of Fertilizer Types on the Growth and Yield of *Amaranthus Caudatus* in Ilorin, Southern Guinea, Savanna Zone of Nigeria." *Advances in Agriculture* 2014.
- Agegnehu, Getachew, Adrian M. Bass, Paul N. Nelson, and Michael I. Bird. 2016. "Benefits of Biochar, Compost and Biochar-Compost for Soil Quality, Maize Yield and Greenhouse Gas Emissions in a Tropical Agricultural Soil." *Science of the Total Environment* pg 295–306.
- Alberto, Diana; Serra, Anne-Antonella; Sulmon, Cécile; Gouesbet, Gwenola; Couée, Ivan (2016). "Herbicide-related signaling in plants reveals novel insights for herbicide use strategies, environmental risk assessment and global change assessment challenges. *Science of the Total Environment* 569–570: 1618– 1628.
- Atwood, Donald, and Claire Paisley-Jones. 2017. Market Estimates." *Pesticides Industry Sales and Usage*.
- Cerda, Artemi. 2021. "Rice Research: Open Access Important of Weed Control and What Chemicals Are Used in Weed Killers?" 9(11): 1000272.
- FAO. 2019. "Climate-Smart Agriculture in Adamawa State of Nigeria." 22.
- Forouzesh, Abed; Zand, Eskandar; Soufizadeh, Saeid; Samadi Foroushani, Sadegh (2015). "Classification of herbicides according to chemical family for weed resistance management strategies—anupdate. *Weed Research*. 55 (4): 334–358.
- G.Y, Jamala,. 2013. "Assessment of Agro-Chemicals Utilization by Small-Scale Farmers in Guyuk, Adamawa State, Nigeria." *IOSR Journal of Agriculture and Veterinary Science* 6(2): 51–59.
- Keteku, A. K., P. Intanon, S. Terapongtanakorn, and R. Intanon. 2019. "Economic Production of Maize under Chemical and Granular Organic Fertilizer with Hormone Mixed Formula, NPK and Organic Fertilizer." *Indian Journal of Agricultural Research* 53(5): 560–65.
- Liu, Xi-qiong et al. 2017. "Acetolactate Synthase-Inhibiting Gametocide Amidosulfuron Causes Chloroplast Destruction , Tissue Autophagy , and Elevation of Ethylene Release in Rapeseed." 8(September).
- Ndaghu, Augustine Anthony, Maimuna Mukthar, and Amurtiya Michael. 2018. "adoption of improved farm practices among maize (*zea mays* L) farmers in Yola, Adamawa State, Nigeria." *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development* 18(1): 261–66.

- Pinho, Carlos. 2014. "The Usefulness of Analytical Procedures - An Empirical Approach in the Auditing Sector in Portugal." *The Usefulness of Analytical Procedures - An Empirical Approach in the Auditing Sector in Portugal* 4(8): 25–33.
- Smith, Keith, David A. Evans, and Gamal A. El-Hiti. 2008. "Role of Modern Chemistry in Sustainable Arable Crop Protection." *Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1491): 623–37.
- Vats, S. (2015). "Herbicides: history, classification and genetic manipulation of plants for herbicide resistance". In Lichtfouse, E. (ed.). *Sustainable Agriculture Reviews 15 Springer International Publishing*. pp. 153–192