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Implementation of stubble in agricultural production: A review

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ABSTRACT

Objective: To elucidate the benefits that agricultural residues or stubble have in agricultural activities, through a bibliographic and objective review that could help to make the actors of agricultural sector aware of the benefits and their correct implementation in production systems.

Design/methodology/approach: A detailed review of scientific articles from the main academic databases and repositories was performed. We took into account aspects such as the use of stubble as plant cover; effects and changes in physical and chemical structure of soil; crop yield and use for livestock feeding.

Results: The use of stubble has beneficial effects on agricultural activities. In agriculture, they have positive effects for the proliferation of beneficial organisms and assimilation of nutrients, which are easily absorbed by plants. Consequently, crop yield is maximized both in quantity and quality terms. In livestock sector, the stubble implement provides nutrients such as proteins, ashes and vitamins, which together with conventional diets, reduce production costs and improve meat and milk production.

Limitations on study/implications: The repertoire of scientific articles related to stubble is very broad, making it difficult to assimilate the information. In Mexico, particularly, more research is needed to inform farmers of the possible uses of stubble.

Findings/conclusions: The use of stubble in agricultural activities generates benefits at ecological and economic levels, which ensure the sustainability and resilience of agroecosystems. Nutritional content of stubble is a function of the species and/or varieties of agricultural species. The lack of knowledge in the management of stubble leads to these being incinerated, releasing particles and toxic and polluting substances for the environment, further favoring the conditions for greenhouse effect.

Keywords: stubble, vegetation cover, yield, sustainability, resilience.

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INTRODUCTION

Stubbles are by-products derived from agricultural activities, which remain on the ground after harvesting and are mainly used as plant covers and for livestock feed [1]. Stubble is mainly linked to the cultivation of corn. The Consultation Agrifood Information System [2], registered 17.5 million tons of corn stubble (15.5 million tons), wheat, triticale, sorghum and oats.

Image by S. Hermann / F. Richter at Pixabay

Cereals are grass-like plants that form the basis of food in many regions of the world. Most important cereals include maize, rye, wheat, rice, sorghum and oats. Maize is the most cultivated and important cereal in Mexico. At the time of corn harvest, the cob is the usable element of the plant, the remaining elements such as stems and leaves, which are considered foliar residues [3].

Agriculture is an economic activity carried out in a large part of the Mexican territory, with international importance. When fields are homogeneous with flat surfaces, agricultural practices such as planting and harvesting are easier to carry out. In rocky or steeply sloping surfaces, besides making these agricultural tasks more difficult, the rain cause erosion, and therefore the soils gradually decrease their productive capacity due to the loss of nutrients.

Soil erosion is one of the many problems facing agriculture and is a serious threat to food sustainability [4]. Cultivating on eroded or degraded soil will result in a poor harvest in terms of quantity and quality. Soil erosion due to hydric factors is the most important type of erosion and is the one that causes the greatest losses, especially in soils that do not have vegetal covers and those that are found on slopes [3].

Residue cover can reduce evaporation of water from the soil surface, thus conserving moisture and increasing the number of days a crop can survive in the absence of rains. Most farmers are unaware of the usefulness that stubble can have, so they resort to burning it, causing pollution to the environment and affecting the nutritional balance of the soil. When stubble is burned, volatile compounds such as carbon dioxide, carbon monoxide, nitrogen oxide, sulfur oxide, methane and aerodynamic particles are produced [5].

Cattle feeding is another secondary activity for farmers that can be economically draining. Stubble also contains nutrients that can be incorporated into animal feed. However, it is important to consider that they are not a substitute for balanced feed, but rather a complement that can help reduce costs. For animal feeding, stubble must be processed: cut, chopped and ensiled, which may require certain machinery or equipment that can be expensive [6].

From an ecological and socioeconomic point of view, the use of stubble becomes essential in sustainable agricultural systems. However, its use is limited by the lack of knowledge and technical advice to farmers. The objective of this research was to elucidate the benefits that agricultural residues or stubble have in agricultural activities. With that aim, we performed a deep bibliographic and objective review that may help to make stakeholders of agricultural sector aware of the benefits and their correct implementation in production systems.

MATERIALS AND METHODS

For this review the following sources were surveyed: JSTOR, ProQuest, Wiley Library, Taylor & Francis, Redalyc, World Wide Web, BioOne, PubMed, Natural Journal, Dialnet, ACS Publications, Springer, Annual Reviews, Scielo and MDPI. The topics of interest were related to agricultural implementation, plant cover, animal production, crop yield and pollution. Information relevant to the searches carried out in the sources consulted is shown in Table 1. It is important to mention that the use of stubble dates back several centuries. Furthermore, the searches also yield stubble information related to disciplines such as sociology, where its use in agricultural sector is not scientifically based.

Table 1. Academic repositories and stubble search features.

Database	Number of publications	Interval of years	Features
JSTOR	18,406	1699-2022	Focused on agricultural sciences. Scientific articles (68%) and book chapters (25%) predominated.
ProQuest	11,056	1805-2020	Dominate scientific articles related to agriculture.
Wiley Library	10,800	1818-2020	Nealy 90% of the sources were scientific articles; 30% of which linked to agricultural production.
Taylor & Francis	5,038	1901-2020	About 50% of scientific articles are related to environment, 15% to geography and 14% to earth sciences.
Redalyc	1,619	2001-2021	Articles mostly in Spanish (95%), mainly Mexico (32%), Colombia (25%) and Argentina (10%). Of them, 30% were related to agrosciences, 9% to biology and 6% to veterinary medicine.
World Wide Web	1,356	? - 2022	Researches performed in the USA acomplisgshed 580 articles. Of them, 30% refer to soil science and management.
BioOne	1,131	1965-2022	Scientific articles related to agriculture and conservation.
PubMed	415	1943-2022	Scientific articles related to agricultural research.
Nature Journal	395	1873-2022	Scientific research focused on agricultural systems.
Dialnet	327	1964-2021	Approximately 77% are scientific articles; 11% is represented by thesis.
ACS Publications	214	1894-2022	Scientific articles related to agriculture and food chemistry.
Springer	187	2005-2022	Scientific articles stand out in the area of agronomy, sustainable development and ecology.
Annual Reviews	100	1934-2019	About 26% were scientific articles related to entomology.
MDPI	79	1966-2022	Of the total, 90% were scientific articles focused on agricultural production.
Scielo	52	2000-2020	Articles are associated with agricultural and biological sciences.

RESULTS AND DISCUSSION

Agricultural implementation and vegetation cover

Agriculture is an economic activity carried out in a large part of the Mexican territory. On flat terrain, activities related to the field and the implementation of agricultural machinery are usually facilitated, but not so on irregular, rocky terrain and with steep slopes. Water erosion in soils induces leaching of nutrients and loss of essential particles (sand, silt, clay) causing low fertility and low productivity of soils with agricultural use [4].

The value of the use of stubble can have significant contributions to producer's economy [7]. In Morocco agricultural systems, cereal stubble can represent 25% of the total production value, taking into account that the irrigation and/or rain conditions are adequate.

Cong *et al.* [8] showed that thickness of ideal mulch or plant cover is up to 20 cm, thus ensuring the retention of a greater amount of water and an increase in temperature, which are factors that regulate and improve seed germination and optimal seedlings growth.

Huang *et al.* [9] evaluated the soils fertility of Loess Plateau, China, where the incorporation of stubble increased nitrogen levels and consequently grain yield of cereals. This translates into increased water and nutrient absorption capacity, which will later provide vigor and productivity to plants, as well as tolerance to abiotic factors, such as frost or drought. Stubble cover is an ideal habitat for arthropods, which feed on weed seeds and release organic matter.

Addition of soybean residues [*Glycine max* (L.) Merr.] and nitrogenous fertilizers in a wheat rotation (*Triticum aestivum* L.) increased NH_4^+ (ammonium) concentrations by 153%, and relative abundance of saprophytic fungi that contribute to the mineralization of plant compounds, which is important since they form the so-called humus. Humus is a mixture of organic compounds that has positive effects on soils by maintaining physical-chemical structure and providing availability of nutrients; Additionally, the amount of ammonium and beneficial organisms increase significantly with the application of nitrogenous fertilizers [10].

In subtropical regions, there is incomplete information on the long-term effects of tillage or soil removal, the use of stubble, and the application of nitrogen fertilizers on the soil. Hernández-Flores *et al.* [11] examined soil effects with conventional tillage, zero tillage, stubble management, stubble burning, and nitrogen fertilization to analyze the impact on microbial flora growth, glomalin, and nitrogen mineralization. Results showed that the aforementioned variables significantly increased with stubble retention and external nitrogen inputs; the increases in glomalin (glycoproteins) had statistically significant increases, this is due to the fact that this compound is a natural sequestrate of carbon and nitrogen, which are essential elements in the synthesis of biomolecules.

Stubble can be used to minimize the problems caused by water erosion, since they work as soil protectors when used as plant covers or mulches [3]. Hernández-Flores *et al.* [11] studied Australian tropical regions over the last 50 years to assess the effects of incorporating stubble into soil and zero tillage. They showed that microbial activity of soil improved due to mineralization of nitrogen, which makes soil nutrients available and can be used by plants [12].

Animal production

Agroecosystems usually use products derived from crops for certain activities related to agriculture. Cereal crops bring about not only grans but also organic residues that can be used as feed for livestock. These residues are important sources of fiber, proteins and minerals [3]. The amounts and percentages of nutrients depend on the crop in question and the parts used as stubble, whether stems, leaves and roots, as well as genetic interactions of livestock with the environment and stubble management [13].

In sorghum, research has been carried out on genetic breeding to release varieties with a dual purpose, grain and stubble production. Thomas *et al.* [14] evaluated dual-purpose sorghum genotypes in Nicaragua and analyzed agronomic variables, highlighting a high protein content in fresh leaves with high heritability indices ($\geq$0.5). The use of stubble has benefits related to chewing, rumination, food particles and liquids in the digestive system [15]. In maize, it is recommended to chop stubble to a size close to 2 cm, the most suitable in practical terms and beneficial for sheep diet [16].

Arellano-Vicente *et al.* [17] analyzed the characteristics of maize stubble compared to different types of weeds in the diet of cattle in La Frailesca, Chiapas, Mexico. Dry matter availability is higher in maize stalks compared to other plant components (leaves, bracts, grain, panicle, and cob). At the end of stubble use, statistical differences were found in the percentage of crude protein and ashes compared to the first five and half days of stubble use. The elements richness of stubble is essential to improve the quality of animal diets.

In Western Australia, the dietary effects of barley (*Hordeum vulgare* L.), lupin (*Lupinus* spp.), canola (*Brassica napus* L.) and wheat stubble on sheep nutrition were evaluated. It was quantified that sheep obtained a weight gain of 89 g day^{-1}, taking as reference the metabolizing energy of wheat (5.9 MJ metabolizable energy kg^{-1} dry matter); barley residues were higher by 5%; 19% higher in lupine and 5% lower compared to canola [13].

Livestock production and rice cultivation are important activities in Thailand. In goat diets it is important to implement cereal stubble. Vorlaphim *et al.* [18] elaborated a diet based on rice stubble plus the incorporation of urea and *Pleurotus ostreatus* to increase the nutritional value. The combination of these three elements had significant effects on goat body weight gain, which was 82.3% higher than the diet that only included rice stubble. The total weight gains with the mixed diet (rice stubble, urea and *P. ostreatus*) was 85% higher compared to the exclusive feeding of rice stubble. However, corn stubble can also contain toxins if not managed properly. López *et al.* [19] reported aflatoxins and mycotoxins, such as deoxynivalenol (0.7 mg kg^{-1}) and T-2 toxin (4.1 mg kg^{-1}) in grain and zearalenone (3.0 mg kg^{-1}) in stems and leaves, by means of two-dimensional thin-layer chromatography. This means a health risk to both animals and humans when consuming contaminated meat.

Crop yield

Rice cultivation is one of the main foods included in the diets of the Asian continent, with China, Bangladesh, Indonesia and India producing more than 500 million tons of rice a year [20]. Consequently, the amount of waste generated by the crop can be a problem that could be difficult to manage in these countries.

In India, technologies have been implemented for the management of rice stubble, where by means of machinery these can be used for vegetable covers or for silage. When rice stubble is managed efficiently, the cost of inputs per acre (0.404 hectares) decreases and crop yield increases significantly, since stubble contributes with organic matter and nutrients to the soil. These contributions function as a substitute in the use of chemical fertilizers, which tend to have a higher cost. However, not all producers have access to agricultural machinery, so it is recommended that producers are organized in cooperatives to reduce the costs related to the acquisition of machinery to handle stubble [21].

China is one of the main producers of rice and wheat worldwide, since it constitutes the staple food in its culture. When stubble is left on the ground, it can cause problems for seed germination, therefore, it should be incorporated after sowing or when the plants have a considerable height. Xu *et al.* [22] determined that the length of the straw (30 mm, finely chopped), the quantity or height of the incorporated stubble significantly influence the yield of the rice crop. Keil *et al.* [23] developed a machine that has the ability to sow wheat on a thick layer of stubble, thus facilitating the timely sowing of cereals, showing a significant saving of 120 dollars per hectare in Punjab, Pakistan. A promising new approach is the *Happy Seeder*, which combines the functions of stubble mulching and seed sowing in one machine. Stubble is cut and collected in front of the seeding tines, flattening into bare soil, and deposited behind the drill as mulch allowing wheat to be sown on rice stubble [24].

Wheat and soybean stubbles were applied at different levels (0.5%, 1% and 2%) to cultivate cucumber, with both types of stubble significantly increasing soil porosity and thus improving aeration and drainage. The treatment with wheat stubble at 2% decreased the electrical conductivity (EC), the opposite was the case for treatments with soybean stubble. By increasing the EC, plants have an easier time absorbing and assimilating nutrients from the soil. In general, wheat and soybean stubble increased yield cucumber crop in quantity and quality [25].

Stubbles also have the ability to incorporate nitrogen into soil, which is one of the main elements for synthesizing proteins. Rice yield is achieved with the contribution of nitrogen from stubble and reduce the cost of chemical fertilizers [26]. The combination of stubble with chemical fertilizers such as urea significantly increases wheat yields and minerals such as nitrogen and organic carbon [27].

A correct stubble decomposition increases soil microbial flora. To achieve such a result, a carbon:nitrogen ratio of 30:35 and a moisture content of 60-65% are required. For stubble decomposition the following genders stand out: *Chaetomium*, *Myrothecium*, *Trichoderma*, *Fusarium*, *Aspergillus*, *Penicillium*, *Trichonympha* and *Clostridium* [28].

Phosphorus (P) is present in stubble and can be released into soil as soluble P or assimilated by microorganisms that carry out the mineralization process. Noack *et al.* [29] analyzed stubble of various cereals in South Australia finding 1-5 kg ha^{-1}. Using nuclear magnetic resonance spectroscopy, it was determined that 50% of P was in the form of soluble orthophosphate, which is easily assimilated by plants and organisms; the remaining 50% phosphorus belonged to phospholipids, nucleic acids and pyrophosphates.

Contamination

Stubble burning in India generates around 150 million tons of CO_2, 9 million tons of CO, 250 thousand tons of sulfur oxide and one million tons of particulate matter (PM2.5 y PM10) [30]. Smog can cause health damage, such as skin and eye irritation, cancer, as well as neurological, coronary and respiratory diseases [5]. When stubble is burned, the amount and efficiency of nitrogenous fertilizers (urea), diammonium diphosphate (DAP, 18-46-00) and monoammonium phosphate (MAP, 11-52-00) are reduced [31].

Additionally, stubble can also be used to generate charcoal and as compost elements, it can even be added to cement mixtures and brick production [5]. In Mexico, studies were also carried out on ethanol production based on corn stubble, despite the fact that the addition to gasoline is effective, the production costs are still high and they are not profitable. In the near future, we expect to develop technology to reduce production costs. It is important that countries have food and energy sovereignty to ensure development, security and socioeconomic prosperity [32].

CONCLUSIONS

Stubble use in agricultural activities generates benefits at ecological and economic levels, which ensure the sustainability and resilience of agroecosystems. The nutritional content of stubble depends on the species and/or varieties of agricultural species. The lack of knowledge in the management of stubble leads to these being incinerated, releasing toxic particles and polluting substances for the environment, further promoting the conditions for greenhouse effect.

Edaphic erosion problems can be mitigated with the use of plant covers or mulches, since these improve humidity conditions, soil physical properties, and provide assimilable nutrients for plants. Moreover, they function as a habitat for arthropods, which reduce the incidence of weeds because they feed on their seeds.

The results of this review show that stubble, together with the addition of other organic compounds and external sources of fertilizers, significantly increase crop yields. Incorporation of stubble to cattle feed has beneficial effects on body weight gain and influences cost reduction. Although not addressed in this article, stubble has also applications in diverse industries including construction, architecture, manufacture and bioenergy.

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