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The Need to Update a Practical Guide Related to the Cycle for Fumigation of Grains as a Function of Research and Technological Progress

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Abstract: This paper describes relevant aspects mainly related to fumigation of grains and cereals as a useful treatment to prevent post-harvest losses and improve food security. At the same time, it highlights a publication entitled: "Guide to fumigation under gas-proof sheets" prepared jointly by FAO and ACIAR in 2004. This guide is special since it is valuable as a reference text and it also contains a CD – ROM with audio visual training material on fumigation. The AGST technical unit of FAO would like to draw attention to the need to update this guide on fumigation in line with the Montreal protocol on the use of fumigants and invites storage and fumigation experts to promote activities in favour of the improvement of food security and environment protection where the INPhO web data base of FAO could play an important role in technical diffusion of this subject matter. Likewise, some FAO experiences and issues of interest related to post harvest matters and fumigation are discussed.

Introduction

The need to preserve grains and cereals after harvesting is a mandatory stage that must be faced by agricultural farmers, middlemen, traders, authorities of the national grain reserves of governments, those responsible for grain milling agro industry and many other stakeholders involved in the food chains related to grains and cereals in order to maintain good-quality grains either for consumption, processing or as a source of seeds for planting. Therefore, a basic infrastructure and application of adequate technical knowledge is essential in order to prevent postharvest losses due mainly to the attack of different pests such as insects, rodents and others.

In fact, postharvest losses could amount to as much as 80 percent, especially in developing countries and in developed countries, although postharvest losses are not as high as in developing countries, significant losses may still occur. In a study carried out by the prevention of post harvest losses programme (PFL) of FAO at the end of the 1980s 80^{th} in Asia, it was discovered that storage is one of the most critical operations where most rice post harvest losses of occur. For a secure preservation of grains during storage, is not only important to have a hermetic structure, but also it is very important to dry the grain properly to a level of safe moisture content before it is introduced into the storage structure. The desirable moisture content for the drying of grains and cereals is shown in the following Table 1.

Table 1.

Product	Final moisture content in storage %
Maize	13.5
Sorghum	13.5
Paddy	13.5
Millet	14.5
Safflower seed	9.5
Linen	9.5
Oilseed rape	7.5
Sunflower seed	10.5
Groundnut (shelled)	8.5
Soybean	12.5

Source FAO publication, 1996: "*Secado de granos y secadoras*"

However during the storage period for dried grains and cereals, biochemical respiration, both aerobic and anaerobic, takes place at a low rate. This biochemical process is described in the following reactions shown in figure 1.

$$C_6H_{12}O_6 + H_2O = 6CO_2 + 6H_2O + \text{Heat (Aerobic respiration)}$$

or

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + \text{Heat (anaerobic respiration)}$$

Fig. 1 Biochemical reactions of respiration for grain and cereal during storage period

In summary, in both cases the respiration biochemical process generate as final products moisture and energy causing an increase of the internal temperature inside the store creating optimal condition for the germination of insect

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eggs and larvae growth at expense of consuming the grains substrate, which in turn provokes the quantitative and qualitative losses of the grains and cereal stored. Therefore, the fumigation process represents a very useful treatment to prevent grain losses during storage. In this context, fumigation becomes an important treatment which deserves special attention, since it allows for the protection the grain against the attacks of insects and as a result increases the shelf life of grains and cereals stored. This paper deals with the most relevant aspects to be considered for appropriate fumigation treatment at small, medium and largescale level. Likewise, this paper draws the attention to the need to have an updated guideline on fumigation which is in line with the technological progress and innovation required for grains and cereals preservation.

Background and Justification

As was mentioned above, the need to preserve the grains and cereals in storage is essential in order to avoid losses and in consequence to improve the food security of the people. This subject is of continuous importance and interest within the food chain of the agricultural sector. In this context, and due to the need to present alternative solutions, as for example, more effective and efficient technologies for protecting the grains and cereals in storage, particularly at the present time when the prices of staple food grains are increasing, this is another reason to justify why it is important to optimise, not only the production of grains and cereals, but also be more efficient in terms of managing and application of technologies at the post harvest period for grains and cereals especially during the storage operations.

Therefore, the Food and Agricultural Organization of the United Nations is concerned about the food security of their member nations and is making efforts through different activities such as projects, programs, regulation norms and publications among others to contribute significantly to improving the standard of life of people so that it is in equilibrium and harmony with the environment.

Fumigation is an important aspect of grain preservation at the small, medium and largescale level, and although it may seem a complex and hazardous technology, it is an excellent system which works effectively and efficiently when it is applied properly.

On this occasion, the Agricultural and Food Engineering Technologies Service AGST of FAO, would like to highlight an FAO publication of interest for the post harvest sector for grains and cereals during storage and which particularly refers to the fumigation treatment. It is of importance for FAO to present this useful publication on fumigation, since due to the fact that the modern trends on grain fumigation place emphasis on reducing the use of chemicals, this publication can be still considered a practical guide to be followed at present by users.

The publication in reference entitled: "Guide to Fumigation Under Gas-Proof Sheets" was produced by FAO in 2004 as a practical guide, which was compiled and prepared by the Australian Centre for International Agricultural Research (ACIAR) in Canberra, Australia. The publication comes together with a complementary multimedia CD – ROM with the same title and it is strongly recommended, in order to obtain more effective results, that the hard copy guide be used in conjunction with the electronic version contained in the CD – ROM.

Given the importance of the fumigation treatment which demands accuracy and precaution vis-vis the protection of human health and the safety of the environment, fumigation treatment must follow a certain protocol with regard to its application, and an acute sense of awareness and responsibility are very important. In this sense, the creation of a global task force of experts, that can contribute to the creation of an updated database and guidelines in line with the efficiency and the protection of health and the environment, is very important.

In fact, this publication guide along with the complementary CD, is very likely be one of the few publications, if not the only one, which have this particular type of content.

It is clear that the present guide on fumigation produced by FAO is a useful guide which contains practical issues based on the long experience and knowledge of many recognized experts. However, it is also appropriate to think that, as some fumigants are in the process of being phased out due to the fact that they cause ozone-layer depletion and due to the the protocol of Montreal, the need to revise and update the fumigation guide also becomes a matter for periodic renewal and, likewise, will need to be replaced periodically.

By means of this paper FAO would like draw the attention of the grain fumigation experts and institutions so that they may propose new ideas that may enrich new concepts for the new version of the fumigation guide. for fumigation. FAO would be open to share future activities in this regard with other partner institutions in order to provide technical support for the prevention of post harvest grain losses and, in consequence, to ensure food security.

Fundamental Aspects to Consider for a Properly Fumigation

In this section the main terms and aspects to consider when fumigation treatment is applied are discussed. These terms and aspects are described in more details in the guideline of fumigation and also by means of the practical videos contained in the CD – Rom, which is the complementary part of the guide prepared by FAO and ACIAR.

For What Reason and for Whom this Fumigation Guide has Been Prepared

the guide has been made to tell and show users how to do undertake fumigation with phosphine and methyl bromide and using gas-proof sheets to treat bag-stacks of grain and cereals, loaded freight containers and products or cargoes like timber and machinery that can be enclosed under gas-proof fumigation sheets. The fumigation technique recommended is supported by effective scientific principles. The guide was designed for people who have some previous training in how to undertake fumigation using gas-proof fumigation sheets. The guide not intended to be a manual for people who do not have experience with fumigation nor to replace any existing local regulations on the use of phosphine, methyl bromide or other fumigants, but the guide may provide a better understanding of these regulations.

Some Terms and Basic Facts about Fumigation

a. Fumigants: these are gases of a normal temperature and due to their toxicity are used to kill pests, because they rapidly penetrate through grains and other commodities. The way fumigants diffuse during fumigation treatment depends on their physical properties. Therefore, it is important to have a good understanding of the properties of the fumigant and how they can affect the results of fumigation.

b. Fumigation: process of adding a fumigant to a fumigation enclosure with the specific purpose of killing pests.

c. Best Fumigation Practices: provide a successful treatment process and results from a practical combination of applying required procedures during fumigation to ensure that people doing the fumigation and people around the area of fumigation remain safe and are not harmed, the environment is not harmed, all life stages of all target pests are killed and the product under treatment is not damaged.

d. Fumigation enclosure: these could be permanent or temporary structures; in any case they must be well-sealed in such a way that they are sufficiently gastight to hold a toxic concentration of the gas fumigant long enough to kill target pests during a specific period of time named *the exposure period*. During the best fumigation practices, fumigation enclosures are checked to ensure that they are well-sealed to hold a fumigant over the required exposure period (s). Permanent fumigation enclosures include purpose-built fumigation chambers, some sealed grain silos, some sealed horizontal grain storages, etc. Temporary fumigation enclosures are commonly created using gas – proof plastic sheets, using a technique called sheet fumigation.

e. The exposure period: is the time required for a specific dosage of fumigant to kill target pests. The exposure period is counted from when monitoring shows that the fumigant concentration reachs an effective concentration minimum of 0. 05 g/m^3 for phosphine and 3 g/m^3 for methyl bromide. The length of the exposure period depends on the type of fumigant, physiological state of the target pest, temperature of the commodities, rate of respiration of the target pest and the dosage of fumigant applied.

f. Half-Loss Time (HLT): the time taken for one half of the original concentration of fumigant to be lost from a fumigation enclosure due to leakage or sorption. The HLT is determined only by monitoring gas concentration.

g. Fumigation sheets (Gas proof sheets, tarpaulins or tarps): are gas-retaining plastic sheets used to hold fumigants inside a fumigation enclosure during the exposure time.

h. Sealing: process which renders the fumigation enclosure gastight.

i. Leakage: is the loss of fumigant gas from a fumigation enclosure

j. Permeation: is the loss of fumigant gas from a fumigation enclosure due to "Gas-proof" Sheets, which are seldom completely impermeable.

k. Diffusion or dispersion: the process whereby a fumigant gas moves from an area of high concentration to an area of lower concentration until it finds the equilibrium concentration.

l. Dosage: describes not only the amount of fumigant gas that mut be introduced, but also the length of the exposure period. It is always expressed in two parts: The amount of fumigant gas required and the period of time. For instances, X g/m^3 for 24 hours or Y g/t (grams/tonne) for 7 days.

m. Equilibrium: occurs in well-sealed enclosures after the dosage is applied, the gas concentration remains stable and equal in all parts of the fumigation enclosure and remains above an established threshold for tolerant life stages of target pests.

n. Concentration: describes the amount of fumigant in the air/atmosphere inside a fumigation enclosure and it is expressed as weight or volume of fumigant gas in a given volume of air. Common concentrations are expressed as grams per cubic metre (g/m^3); milligrams per litre (mg/L) or parts per million (ppm).

o. Monitoring: is the process of measuring the concentration of fumigant gas inside a fumigation enclosure and the area surrounding a fumigation enclosure. There are different devices and companies offering these products.

p. The threshold limit value (TLV) (occupational exposure standard) is the maximum concentration of fumigant gases established to which workers may be repeatedly exposed in the work place without harmful effects. The TLV in many countries has been set at: 0.3 ppm (0.0004 g/m^3 or 0.42 mg/m^3) for phosphine; 5.0 ppm (0.02 g/m^3 or 19.4 mg/m^3) for methyl bromide.

q. Sorption (absorption and adsorption) is the uptake of fumigant gas by the product being fumigated. When sorption is so great and concentration of fumigant inside the enclosure is reduced to less than minimum effective, it becomes impossible to kill the target pests. This situation must be corrected by the addition of more gas (dosage corrections), otherwise the treatment will fail.

r. De-sorption: is the reverse of sorption and it is the release of sorbed fumigant that was fumigated and it normally occurs at the end of fumigation or during aeration or the ventilation stage. Fumigants with a high boiling point, as for example methyl bromide, tends to be sorbed more and remain as residue for longer lengths of times than fumigants with a low boiling points such as phosphine.

s. Residues: are very small quantities of chemical left in a product after it has been fumigated. These could include, chemical from which fumigant gases are generated (e.g. aluminium phosphide formulations, fumigant gas, e.g. unchanged methyl bromide after a fumigation undertaken at a low temperatured and any compound formed when a fumigant gas reacts with the product being fumigated.

t. Aeration (airing or ventilation): is the process at the end of the exposure period, after the fumigation enclosure is unsealed, when fumigant gas desorbs and diffuses out from the product fumigated and from the fumigation enclosure.

u. Clearance: is the procedure after the aeration period when the fumigator tests the air in the workspace to make sure that the concentration of fumigant has fallen to or below the safe level and declare that the area is safe for workers.

v. Danger (exclusion, hazard or risk) area: any area near to a fumigation enclosure into which fumigant gas may escape or diffuse in dangerous concentrations is called a danger area. This area must be clearly marked in accordance with regulations.

w. The label: this is when it has been demonstrated that a chemical can be used in compliance with national regulators governing the use of insecticides, the chemical is registered for use and granted a label by a national agricultural chemical registration agency.

x. Material Safety Data Sheets (MSDS): describe the properties and hazards of a material or substance, including its identity, normal uses, ingredients, physical and chemical properties, stability, reactivity, health hazard, first aid treatment, storage, ecological information and transport and disposal considerations.

Responsibilities vs Good Fumigation

The fumigation process and its success are generally assumed to be the responsibility of only the fumigator. However this is not so, because successful fumigation relies on all people involved in any fumigation treatment and includes: the customer, the fumigator, the transport contractor and the regulatory agencies that directly affect the conduct of the fumigation.

a. Customer: they must choose qualified, approved and currently valid certification to perform fumigation among others.

b. Fumigators must have a valid license, skills and competencies, safe equipment and others.

c. Transport contractor (s): they must obtain from the customer and the fumigator information about the fumigation, treatment dates, length of the exposure and aeration period, etc.

d. The regulatory agencies: national and international agencies (e. g. quarantine authorities with an interest in the way that fumigation treatment is undertaken. This may be through legislation, regulation, training and retraining, and or license.

e. Other parties: people involved in fumigation treatment may vary from place to place, for instance, in some countries the police, the fire brigade and neaby hospitals are involved.

Monitoring

This is the process of measuring the concentration of fumigant gas, both inside the fumigation enclosures and in the area surrounding a fumigation enclosure.

a. monitoring equipment: a wide variety of equipment is available for measuring phosphine and methyl bromide concentrations. The equipment must be suitable for monitoring, with regard to the concentration range, the concentration involved in the work place and the fumigant concentrations reached during fumigation treatments.

b. Fumigant concentration in the health and safety range: for measuring phosphine and methyl bromide concentration, that is around the threshold limit value which is 0.3 ppm for phosphine and 5 ppm for methyl bromide. Different devices can be used for these purposes such as gas detectors, electronic gas – measuring equipments, dosimeters. For best fumigation practices, monitoring is essential.

Advantages and Disadvantages of Phosphine and Methyl Bromide Fumigants and Other Treatments for Grain Protection

Before a decision is taking on the selection of a fumigant, it is necessary to make an analysis of the properties and characteristics of each one and the characteristics of the product to be fumigated. Contracts or regulations may require that a specific fumigant must be used, if not so, then it is always advisable to choose the better fumigant for the job.

a. Phosphine.

Advantages:

· Not an ozonedepleting substance (environmentally safe);

· If properly used, leaves residues of no commercial significance;

· Simple application procedure using existing expertise, training and manuals;

· Disperses rapidly inside the enclosure and no fan required;

· Air – off easily after treatment and relatively easy and safe for transport in original packages;

· Is cheap;

· Not known to affect germination.

Disadvantages:

· Long exposure and airing period up to 8 days or more;

· Less effective when used at temperatures below 15℃;

· Use on a longterm basis is threatened by the development of resistance;

· Repeated application of tablets or pellets into grains may leave residues above the maximum residue limit (MRL);

· Ease of application and misunderstanding of gas loss have led to misuse and over – reliance on a single method.

b. Methyl bromide

Advantages:

· Rapid kill with 24 hours exposure broad spectrum;

· Existing expertise and training and manual.

Disadvantages:

· Cumulative poisons in humans;

· Less effective at temperatures below 10℃;

· A strong ozonedepleting substance and it will be limited to critical uses including quarantine and pre-shipment treatment. It has been phased out in developed countries and in 2015 will be phased out in developing countries;

· Leaves residues of commercial importance;

· Application fairly complex requiring electricity;

· Must be vaporised and delivered as a hot gas;

· Require fan for effective diffusion inside the enclosure;

· Airs off slowly and requires fan;

· Supplied in heavy cylinders and relatively difficult to transport;

· Becoming expensive due to the intentional phasing out process;

· Germination can be affected (varies with seeds and moisture content)

c. Other treatments

Controlled atmospheres: These are available for using as alternatives to methyl bromide. Techniques of application have been developed that allow them to be used with grain stored in bags. Controlled Atmospheres are divided into two general classes:

1. High carbon dioxide (CO_2), in which carbon-dioxide concentrations are increased to around 70% – 80%.

2. Low oxygen (O_2), where the oxygen is reduced to 1% or less.

In general, high carbon dioxide controlled atmospheres are more commonly used for des-infestation than nitrogen-based, low-oxygen controlled atmospheres because:

- They are effective over a large concentration range;
- They can be applied in a "single shot" (unlike low oxygen);
- There is a greater need for gas tightness using low oxygen atmospheres;
- The exposure period using controlled atmospheres are much longer than those required for methyl bromide or even phosphine.

At atmospheric pressure has been adequate to disinfect bagged commodities using the sealed – stack technique, this technique requires a high level of sealing to maintain carbon dioxide at the required concentration over a minimum of a 15day exposure period under tropical conditions. This technique has been successfully used in Indonesia and Vietnam for milled rice and is recommended for des-infestation of bagged organic and biodynamic grains which are becoming important in overseas markets.

Hermetic Storage

According to Varnava et al., 1995; Anon. 2002, hermetic storage, is a sstore technique used since ancient times and it is still has widespread use in subsistence agriculture, using natural materials for construction. The modern approach to the use of hermetic storage relies on plastic gastight liners to provide the hermetic storage enclosure. During hermetic storage, grains are placed in hermetic sealed enclosures that prevent air from entering or leaving. Inside the enclosure the natural respiration of the grain and any associated insects and fungi occurs. Two things happen: a) It reduces the oxygen content; b) it raises the carbon dioxide to insecticidal levels. These effects control or eliminate insect infestations. This process works better with warm conditions and well-dried grains. Modern, sealed, plastic hermetic enclosures allow grains to be stored safely, to remain fresh, free of insect infestations and to maintain the ability to germinate. Good storage results have been achieved with beans, cocoa, coffee (green), dried chillies, flour, maize, milk powder, millet, paddy, pulses, milled rice, seeds, sorghum, teff, wheat and wheat bran.

The Experience of FAO – with the Household Metallic Silos for Food Security.

The Agricultural and Food Engineering Technologies Service has introduced the household metallic silos in about 17 countries of Africa, Asia and Latin America in the last ten years. The household metallic silo is a key post harvest technology in the fight against hunger and to obtain food security. The household metallic silo may hold between 100 and 3 000 kilos of grains. A silo with a capacity of 1 000 kilos can conserve the grain needed to feed a family of five persons for one year. The silo has many advantages, including protection against rodents and other pest attacks and it is airtight and permits non-residual fumigation.

For the conservation of grains, small farmers who have benefited from silo technology are aware of that situation, and they follow a standard procedure on how to fumigate properly using the small metallic silo. This procedure includes placing the phosphine tablets on an open little paper bag on the internal surface of the grain. Normally, one tablet for each 227 kilos of silo grain capacity is recommended. For instance, a silo of 1360 kilos would need six tablet regardless as to whether it is full or not with grain.

The strategy of FAO of introducing the silo to benefited countries includes training on construction, use and handling of the household metallic silo. The fumigation recommended is the use of the phosphine treatment and hermeticity is achieved using adhesive tapes, strips of rubber or even tallow or soap. Likewise, on each silo manufactured a label must be attached to the body of the silo indicating how to use and manage the silo properly for storage of grains and cereals with emphasis on fumigation procedures. The experience with the metal silo of 120 kilos in Bolivia even demonstrated that the store and fumigation of potato seeds was adequate without affecting germination capacity.

Conclusions and Recommendations

This paper shows some relevant aspects on fumigation contained in the publication titled: "Guide to Fumigation Under Gas-Proof Sheets" produced by FAO and ACIAR in 2004.

Very likely, this is one of the few publication, if not the only in its type, related to good practices of fumigation and presented in two complementary forms: a practical hard copy guide and a useful CD – ROM with audio – visual training material.

It is a useful tool for agricultural farmers, traders, and technicians among others to prevent postharvest losses in storage and to enhance the food security through a reliable technical guide on fumigation.

Given the periodic needs to update a fumigation guide in line with the international agreements such as the Montreal protocol to protect human health and the environment, it would be highly recommendable to create a task force committed to taking care of keeping abreast of the new modern trends in this area, with emphasis on fumigation, and which could update the guide. Also, FAO would be willing to share and support these activities.

The Information Network on Post harvest Operations, INPhO web site of FAO sited at: http://www. fao. org/inpho/could be a database platform to share and update issues on fumigation treatment and progress.

Through this paper, the AGST technical unit of FAO would like to reconfirm the interest to share valuable experiences on the subject of fumigation and grain store and take this opportunity to express to the participants of this conference the idea of thinking about new ideas and sharing these with others in the future.

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