DOI:10.6660/TESFE.1999024 台灣昆蟲Formosan Entomol. 19: 279-291 (1999) 研究報告 Research report

Formosan Entomologist
Journal Homepage: entsocjournal.yabee.com.tw

Vertical Penetration and Distribution of Phosphine in Corn and Sorghum Stored in Steel Silos 【Research report】

磷化氫在鐵質雜糧圓筒倉之垂直穿透及分布【研究報告】

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Received: 1999/03/26 Accepted: 1999/04/28 Available online: 1999/09/01

Abstract

Silos of 10.55 m in diameter and 12 m in height were made of corrugated circular steel for corn or sorghum storage.Some were equipped with circulatory systems consisting of a plastic pipe 10.16 cm (4 in)in diameter from the top to the bottom.Before loading,two sets of gas sampling lines,4 mm in diameter,containing five lines each,were installed in the center and on the circumference of the silo.The openings in each set were at depths of 0,3, 6,9 and 12 m.The gas samples were measured using an EC80 phosphine monitor every 24 h after fumigant application.Phosphine was generated by Detia bag blankets containing 57.6% aluminum phosphate placed on the surface of the grain mass.Generally,the highest concentration of phosphine was obtained 24 h after application in each silo.In silos without a circulatory system,phosphine penetrated down to the bottom through interstitial spaces in the corn or sorghum column.The concentration at the surface,where application was made, was the highest at 24 h.The concentration dropped thereafter due to diffusion,adsorption and decomposition.The deeper into the column,the lower the phosphine concentration was. In each measurement during 24-120 h after fumigant application,the ratios of the highest to lowest phosphine concentration,was between 1:0.02 and 1:0.14,i.e.,the lowest phosphine concentration was only 2-14%of the highest.In silos with a circulatory system,phosphine was sucked into an aeration pipe from the top and sent to the bottom of the silo,then moved upwards through the grain mass.During 24-120 h after fumigant application,the ratios of the highest to lowest phosphine concentration was within 1:0.81 and 1:0.98,i.e.,the lowest concentration was 81-98%of the highest.In the circulatory silo,mortality rates for test insects placed on the surface of grain or insects obtained from grain samples showed 100% control.

摘要

儲藏玉米或高梁等雜糧之鐵質圓筒倉，直徑10.55 m，高12 m。使用氣體循環裝置之倉庫，從倉外倉頂加裝一10.16 cm (4 in)塑膠管至地面，接一送風機通至倉底通風道，形成一密閉氣體循環系統。兩組外徑4 mm之氣體採樣管各5根，於空倉時，一組裝於中央，另一於內緣。各組採樣管在倉內一端分別開口於0、3、6、9及12 m等深度；另一端通至倉外。施藥後每24 h，採取各層深度之氣體樣品，送入EC80型磷化氫偵測器偵測磷化氫氣體濃度，以瞭解其垂直穿透性及在倉內之分布。燻蒸時，含磷化鋁57%之Detia bag blanket施放於積穀表面。藥劑與空氣中之水分作用，產生磷化氫氣體。施藥後24 h，各試驗倉磷化氫氣體濃度最高。沒有氣體循環之倉庫，磷化氫氣體藉由重力及擴散作用由積穀表面向下穿透。施藥後24 h，在積穀表面之磷化氫濃度最高，以後因氣體擴散、吸附及分解，磷化氫氣體濃度逐漸降低。在穀層中，往下深度增加，磷化氫濃度逐漸降低。在施藥後24-120 h間，每次偵測得各層深度之磷化氫氣體，其最高與最低之濃度比為1:0.02-1:0.14，即磷化氫之最低濃度僅為最高之2-14%。氣體循環之倉庫，磷化氫氣體由倉頂吸出，由通風管送至倉底，再經積穀上行。施藥後24-120 h，每次測得各層磷化氫氣體，其最高與最低之濃度比為1:0.81-1:0.98，即磷化氫之最低濃度為最高之81-98%。在氣體循環裝置之倉庫，不論對預置於積穀表面之玉米象(Sitophilus zeamais Motschulsky)或擬穀盜(Tribolium castaneum (Herbst))，或積穀表面穀樣中害蟲，經燻蒸後，防治效果均達100%。

Key words: steel silo,phosphine,vertical penetration and distribution,corn,sorghum

關鍵詞: 鐵質圓筒倉、磷化氫、垂直穿透及分布、玉米、高梁

Full Text: PDF(0.81 MB)

中華昆蟲 19: 279-291 (1999)
Chinese J. Entomol. 19: 279-291 (1999)

磷化氫在鐵質雜糧圓筒倉之垂直穿透及分布

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摘 要

儲藏玉米或高粱等雜糧之鐵質圓筒倉，直徑10.55 m，高12 m。使用氣體循環裝置之倉庫，從倉外倉頂加裝一10.16 cm (4 in)塑膠管至地面，接一送風機通至倉底通風道，形成一密閉氣體循環系統。兩組外徑4 mm之氣體採樣管各5根，於空倉時，一組裝於中央，另一於內緣。各組採樣管在倉內一端分別開口於0、3、6、9及12 m等深度；另一端通至倉外。施藥後每24 h，採取各層深度之氣體樣品，送入EC80型磷化氫偵測器偵測磷化氫氣體濃度，以瞭解其垂直穿透性及在倉內之分布。燻蒸時，含磷化鋁57%之Detia bag blanket施放於積穀表面。藥劑與空氣中之水分作用，產生磷化氫氣體。施藥後24 h，各試驗倉磷化氫氣體濃度最高。沒有氣體循環之倉庫，磷化氫氣體藉由重力及擴散作用由積穀表面向下穿透。施藥後24 h，在積穀表面之磷化氫濃度最高，以後因氣體擴散、吸附及分解，磷化氫氣體濃度逐漸降低。在穀層中，往下深度增加，磷化氫濃度逐漸降低。在施藥後24～120 h間，每次偵測得各層深度之磷化氫氣體，其最高與最低之濃度比爲1:0.02～1:0.14，即磷化氫之最低濃度僅爲最高之2～14%。氣體循環之倉庫，磷化氫氣體由倉頂吸出，由通風管送至倉底，再經積穀上行。施藥後24～120 h，每次測得各層磷化氫氣體，其最高與最低之濃度比爲1:0.81～1:0.98，即磷化氫之最低濃度爲最高之81～98%。在氣體循環裝置之倉庫，不論對預置於積穀表面之玉米象(*Sitophilus zeamais* Motschulsky)或擬穀盜(*Tribolium castaneum* (Herbst))，或積穀表面穀樣中害蟲，經燻蒸後，防治效果均達100%。

關鍵詞：鐵質圓筒倉、磷化氫、垂直穿透及分布、玉米、高粱。

前 言

禾穀類包括水稻、玉米、高粱、小麥及大麥等作物之種子，含豐富之澱粉，是人類或動物基本熱能來源。一般穀類有一定栽培時期，且需要經過一定生長期，才能收穫。可是，人類或動物對穀類的需求是持續性的。因此，收穫後的穀類需要儲藏，以供每日之需。此外，水旱等天災，或其他如戰亂時有發生，政府或民間尚需提供定量之安全儲糧，以供急需。

近三十年來，臺灣畜產與水產養殖事業

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蓬勃發展。玉米則為動物飼料之主要原料，平均每年進口約500萬公噸。由於國民飲食習慣改變，及稻穀增產結果，使得稻米產量供過於求。自七十三年起，政府推行稻田轉作，種植玉米及高粱等雜糧，以調節糧食供需。這些雜糧年產量約40萬公噸，對於調節糧食生產與供需，貢獻良多。

國產雜糧收穫後，向以袋裝平倉儲藏。袋裝作業比散裝用較多的儲存與處理空間。更由於農村勞力逐漸老化與短缺，因此，採用省工，管理方便，自動化儲運措施，勢在必行。而利用鐵質圓筒倉散裝儲運，可增加穀物處理速度，提高儲運效率，對於儲存空間更能有效利用，此種儲運方法已被普遍接受(Shaw *et al.*, 1993）。

穀物儲藏期間，常遭昆蟲、菌類、鳥類及鼠類等生物為害，而造成質與量的損失。為害倉儲穀物之昆蟲，如象鼻蟲類(*Sitophilus* spp.)、穀蠹(*Rhyzopertha dominica* (Fabricius))及麥蛾(*Sitotroga cerealella* (Olivier))等內食性昆蟲，直接為害穀粒胚乳，而造成穀物重量損失。有關儲藏穀物之重量損失估計，有許多報告（Adams, 1977; Harris and Lindbald, 1978）。據 Wilbur and Mills（1978）之估計，世界上儲藏穀物之重量損失約為總產量之5～10%。國內儲藏稻穀由於害蟲為害之損失，早期報導儲藏5～7個月損失約6% (Liang *et al.*, 1954)。後來由於倉儲環境改善及適當之蟲害管理，Hsei *et al.* (1980)報導，儲藏一年之損失約2%以下。Shaw *et al.* (1993)報導玉米及高粱分別經38日及116日儲藏，乾物質損失0.5%；經107及155日之儲藏，損失1%。由是觀之，雜糧中尤其是玉米儲藏期之損失更形嚴重。

粉斑螟(*Cadra cutella* (Walker))、麥蛾、印度穀蛾(*Plodia interpunctella* (Hubner))、鋸胸粉扁蟲(*Oryzaephilus surinamensis* (L.))及角胸粉扁蟲(*Cryptolestes ferrugineus* (Stephens))等昆蟲，除為害穀物之胚乳外，尚可為害胚芽，而大幅降低穀粒活性（Robert, 1961）。種用穀物受儲藏害蟲之為害，因發芽率降低，對其品質及經濟價值影響至鉅。

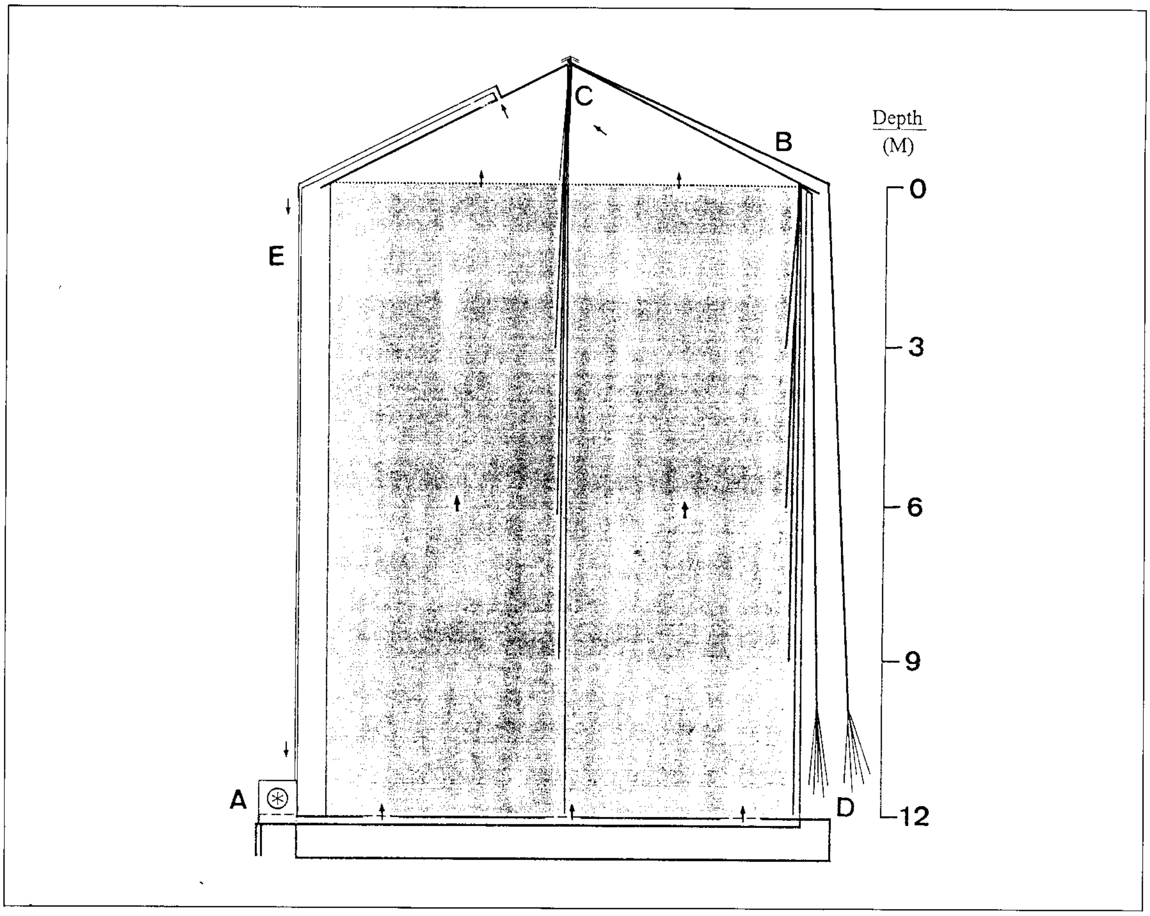
積穀害蟲留下蟲糞、蟲屍、碎片、蛻、繭或粉屑等於積穀中，所造成之污染，均有損儲藏穀物之品質。此外，擬穀盜或扁擬穀盜(*Tribolium confusum* Jacquelin du Val)位於胸部之腺體，分泌具有辛辣臭味之物質，而糞便中亦含有尿酸物質（Roth, 1943; Loconti and Roth, 1953），都會影響積穀之品質。此外，因穀物為熱不良導體，昆蟲在積穀中生長繁殖，代謝所產生之熱，不易被傳導至倉外。遂於倉內形成熱點（Sinha, 1961; Howe, 1962）。因周圍環境溫度較高，促使昆蟲繁殖迅速，代謝旺盛，更使穀溫上昇。同時加速微生物活動及穀物速呼吸作用，結果不利穀物之儲藏。

圓筒倉儲藏雜糧，穀層深厚，容積巨大，每倉約1000 m^3。害蟲發生時，固態磷化鋁方便施用於積穀表面。當磷化鋁與空氣之水分作用時，產生磷化氫氣體，而達到殺蟲效果。一般言之，氣體燻蒸劑具有良好之擴散性及穿透性。實際應用時，因倉庫空間龐大，儲藏之穀物對燻蒸劑擴散造成阻礙。此時，燻蒸劑分布均勻程度，會影響燻蒸效果。磷化氫雖較空氣重1.2倍，可藉重力自然下降。許多文獻報導(Lin *et al.*, 1966; Halliday and Kazaure, 1968; Peng, 1980; Williams *et al.*, 1996)，磷化氫擴散確實受到燻蒸物品之阻礙，在垂直方向不同深度，分布有明顯之差異。本文報導以實倉試驗，探討磷化氫由積穀表面向下穿透，到達倉底12 m之分布結果，以及利用循環裝置對磷化氫分布之影響。

材料與方法

試驗穀倉為嘉義縣義竹鄉農會之鐵質圓筒倉（圖一）6個，其垂直面由鐵質弧形浪板以螺絲釘固定而成。每倉體積約1000 m^3，盛裝國產高粱或玉米，滿倉時穀深12 m。燻蒸試驗於9～11及3～5月間實施。氣體循環裝置之倉庫，在屋頂斜面上開一孔，按裝直徑10.16 cm (4 in)之塑膠管（圖一E），沿屋頂及牆邊下至地面，接一0.5 HP PB 9型防爆馬達(2850 rpm)（圖一A），再接地面之通風系統，形成一密閉循環系統。空倉時，倉內中央（圖一C）及內緣一側（圖一B）敷設直徑4 mm之塑膠管各一組，每組5根，作為氣體取樣管。各組在倉內之開口分別位於0、3、6、9及12 m之深度。所有氣體取樣管之另一端，通至倉外（圖一D）。

燻蒸劑為德燻寶含磷化鋁57%，每包34 g，100包裝成一長條，稱為Detia bag blanket。使用時，攤開平放於積穀表面。使用劑量為9.69 kg a.i./倉(500包/倉)，5.814 kg a.i./倉(300包/倉)，或3.876 kg a.i./



圖一　試驗鐵質圓筒倉剖面圖及附件。

Fig. 1. Profile of steel silo and accessory parts for experiment. A: aeration fan; B, C: gas sampling lines on circumference and in center, respectively; D: outer end of gas sampling lines which connect to phosphine monitor; E: aeration pipe.

倉(200包／倉)。空倉使用量0.5814 kg a.i./倉(50包／倉)，一倉施於倉底，另一倉懸掛於倉頂。

含磷化鋁之德燻寶袋包，施放於積穀表面後，與空氣水份作用時，產生之磷化氫氣體，即瀰漫於積穀表面。循環系統馬達啟動時，磷化氫氣體被吸進塑膠管，並下行至倉底。通過積穀後再上升至倉頂，形成一密閉式循環系統。循環系統馬達未啟動時，即與一般倉一樣，無氣體循環功能。此時，磷化氫氣體藉重力及擴散性，經由穀粒間隙，向下分散。偵測各層深度磷化氫氣體濃度(ppm)，將倉外氣體取樣管接於空氣幫浦，抽取倉內各點之氣體樣本，送至磷化氫偵測器（Model EC80 Phosphine Fumigation Gas Monitor）。施藥後每24 h，偵測倉內各點之磷化氫濃度一次。

害蟲防治效果之評估有二。其一於燻蒸前在玉米或高粱倉之積穀表面，東、西、南、北及中五點，採取穀樣各3包。每包容量1公升，攜回實驗室，分析穀中之害蟲種及數量。燻蒸開倉10日後，於同點同法採樣分析。其二為燻蒸前，以實驗室飼養之玉米象(*Sitophilus zaemais* Motschulsky)及擬穀盜(*Tribolium castaneum* Herbst)成蟲40隻，置於布包中，並放些糙米，預置於積穀表面。每倉15包，待燻蒸後取出，檢查死亡率。此兩種害蟲評估法，僅對循環系統倉及對照倉實施。

結　果

玉米倉施用磷化鋁於積穀表面後，所產生之磷化氫氣體，經過不同時間，在倉內之分佈列於表一至表三。没有氣體循環之玉米倉，施用磷化鋁5.814 kg a.i./倉(300包／倉)24小時，倉內各點磷化氫氣體濃度在施藥之積穀表面，即0 m處最高，為1683～1763 ppm(表一)。隨深度增加，濃度逐漸降低。在底層，即12 m處，僅34～42 ppm。經48 h，積穀表面施藥處之磷化氫濃度降至485～523 ppm，在12 m處，只有32～53 ppm。

使用氣體循環裝置之玉米倉，施用磷化鋁9.69 kg a.i./倉(500包／倉）於積穀表面，經過24 h，磷化氫之濃度最高，達到1246 ppm（表二)。施藥後28 h，各偵測點之磷化氫濃度都在900 ppm以上。至48 h，仍有450 ppm。同樣有氣體循環之玉米倉，當磷化鋁使用量減少為5.814 kg a.i./倉（300包／倉)，倉中各點磷化氫之濃度，在24 h，倉內各點之磷化氫濃度達最高為880 ppm（表三)；至48 h，仍有320 ppm以上。

高粱倉施用磷化鋁於積穀表面後，經過不同時間磷化氫在倉內之分布如表四及表五所示。表四顯示無氣體循環之高粱倉，施用磷化鋁3.876 kg a.i./倉(200包／倉）於積穀表面後，倉內各點磷化氫之分布。施藥後24 h，氣體濃度在施藥之積穀表面之0 m最高，為1132～1231 ppm。往下深處濃度，逐漸降低。24 h，底部尚未測得磷化氫。

氣體循環之高粱倉，施用磷化鋁9.69 kg a.i./倉(500包／倉）於積穀表面後，磷化氫在倉內之分布如表五所示。施藥後磷化氫之濃度遞增，至27 h最高，各點濃度達到1430 ppm以上。至72 h，仍有730 ppm。

鐵質圓筒倉空倉時施用磷化鋁0.969 kg a.i./倉(50包／倉)，磷化氫之垂直分布列於表六。在48小時內，各點均維持在47至82 ppm。

燻蒸前，預置於玉米倉積穀表面之供試昆蟲，包括玉米象及擬穀盜成蟲，經燻蒸後之死亡率列於表七。這些昆蟲死亡率達100%，而對照組之玉米象及擬穀盜之死亡率分別為3.8及9.2%。預置於高粱積穀表面之

表一　無氣體循環之玉米倉於施用磷化鋁5.814 kg a.i./倉(德燻寶300包)於積穀表面後，倉內磷化氫之濃度(ppm)分布

Table 1. Concentration of phosphine at various times after aluminum phosphate application at 5.814 kg a.i./silo to the surface of corn in steel silos without a circulatory system

Depth (m)	Concentration (ppm) of PH_3 at various times (h) after AlP applied				
	24	48	72	96	120
Center					
0 (surface)	1683	485	257	120	27
3	580	398	327	143	26
6	244	182	155	90	20
9	141	72	49	22	11
12 (bottom)	34*	32*	55	19*	8*
Circumference					
0 (surface)	1763#	523#	255	133	13
3	687	463	357#	152#	49
6	312	261	167	117	59#
9	216	119	81	34	26
12 (bottom)	42	53	42*	38	20
Highest/lowest	1:0.02	1:0.06	1:0.12	1:0.13	1:0.14

#, * Indicate the highest and lowest phosphine concentrations, respectively, measured each time.

表二　有氣體循環之玉米圓倉於施用磷化鋁9.69 kg a.i./倉於積穀表面後，倉內磷化氫之濃度(ppm)分布

Table 2. Concentration of phosphine at various times after aluminum phosphate application at 9.69 kg a.i./silo to the surface of corn in steel silos with a circulatory system

Depth (m)	Concentration (ppm) of PH_3 at various times (h) after AlP applied						
	24	28	48	54	68	96	120
Center							
0 (surface)	1060	953	492#	363*	183*	55	18
6	1184	965#	477	363*	187	55	19
12 (bottom)	1024*	950	483	372	187	54*	18
Circumference							
6	1202	930	464	370	195	56	17*
12 (bottom)	1246#	927*	455*	372#	197#	57#	21#
Highest/lowest	1:0.82	1:0.96	1:0.93	1:0.98	1:0.93	1:0.95	1:0.81

#, * Indicate the highest and lowest phosphine concentrations, respectively, measured each time.

試驗昆蟲，死亡率均達100%；對照倉之死亡率分別為12.4及4.4%。

至於玉米倉積穀表面之穀樣，經燻蒸後之死亡率列於表八。燻蒸後42日，大部分玉米穀樣中，没有成活昆蟲，僅有少數象鼻蟲仍成活。高粱燻蒸後20日，積穀表面穀樣有少量角胸粉扁蟲之活蟲(表九)。對照倉中之角胸粉扁蟲及鋸胸粉扁蟲為第二性害蟲，燻蒸後密度顯著增加，而象鼻蟲及穀蠹等第一試驗次性害蟲，密度降低。

討　　論

燻蒸是利用氣態化學藥劑，經由害蟲之呼吸系統進入蟲體內而產生殺蟲作用。雖然氣態之燻蒸劑，具良好之擴散性及穿透性，但是實際應用時，倉庫空間龐大，穀層深厚，會阻礙氣體之擴散速度。因此，燻蒸劑

表三　有氣體循環玉米倉於施用施用磷化鋁5.814 kg a.i./倉於積穀表面後，倉內磷化氫之濃度(ppm)分布

Table 3. Concentration of phosphine at various times after aluminum phosphate application at 5.814 kg a.i./silo to the surface of corn in steel silos with a circulatory system

Depth (m)	Concentration (ppm) of PH_3 at various times (h) after AlP applied						
	24	28	48	54	68	96	120
Center							
0 (surface)	760*	746#	371#	235#	108#	21#	7#
6	770	685*	330	211	96	19	5
12 (bottom)	790	704	323	211	100	19	5*
Circumference							
6	880#	710	322*	208	94*	19	6
12 (bottom)	830	705	328	207*	97	19*	7
Highest/lowest	1:0.86	1:0.92	0.87	1:0.88	1:0.87	1:0.90	1:0.71

#, * Indicate the highest and lowest phosphine concentrations, respectively, measured each time.

表四　無氣體循環之高粱倉於施用磷化鋁3.876 kg a.i./倉於積穀表面後，倉內磷化氫之濃度(ppm)分布

Table 4. Concentration of phosphine at various times after aluminum phosphate application at 3.876 kg a.i./silo to the surface of corn in steel silos without a circulation system.

Depth (m)	Concentration (ppm) of PH_3 at various times (h) after AlP applied				
	24	52	78	96	120
Center					
0 (surface)	1231#	380	239#	61	36
3	585	251	136	63#	39#
6	68	56	48	30	23
9	68	83	45	20	15
12 (bottom)	0	36	27*	12	6
Circumference					
0 (surface)	1132	505#	225	56	24
3	204	123	202	40	33
6	120	92	83	45	27
9	58	47	48	41	20
12 (bottom)	0*	34*	28	4*	2*
Highest/lowest	1:0	1:0.07	1:0.11	1:0.08	1:0.05

#, * Indicate the highest and lowest phosphine concentrations, respectively, measured each time.

有效成份能否分布均勻，會影響燻蒸效果。

磷化鋁分解速度由偵測磷化氫濃度得知，24 h濃度最高度(表一至三)，表五顯示27 h最高。Hsieh and Kao (1975)報導，使用低劑量磷化鋁時，24 h磷化氫濃度最高；高劑量時，在48 h磷化氫濃度最高。

在沒有氣體循環之玉米倉，施用磷化鋁24 h後所產生之磷化氫，在0 m深，即施藥之積穀表面，氣體濃度最高，為1763 ppm (表一)。磷化氫較空氣重1.2倍，藉由重力，往下擴散。在垂直方向，很明顯地，往下漸深，磷化氫濃度逐漸降低。至底層12 m處，濃度最低，僅34 ppm。此時，倉內磷化氫之最高與最低濃度比為1:0.02。即最低濃度僅有最高濃度之2%。至48 h，積穀表面之磷化氫濃度降低很多，只有523 ppm，而在12 m處，僅有32 ppm。此時最高與最低之濃度比為1:0.06。至120小時，最高與最低之濃度比

表五　有氣體循環之高粱倉於施用磷化鋁9.69 kg a.i./倉於積穀表面後，倉內磷化氫之濃度(ppm)分布

Table 5. Concentration of phosphine at various times after aluminum phosphate application at 9.69 kg a.i./silo to the surface of sorghum in steel silos without a circulatory system

Depth (m)	Concentration (ppm) of PH_3 at various times (h) after AlP applied								
	3	5	7	9	24	27	30	48	72
Center									
0	261	492	680	820	1450	1473	1390	1236	755
6	159*	353*	512*	659	1346*	1457	1460	1220*	747
12	195	393	553	657*	1369	1437*	1420	1230	734*
Circumference									
0	231	522#	742#	816	1446	1460	1380*	1225	765
6	213	405	611	720	1420	1465	1480	1250#	770#
12	323#	491	667	851#	1505#	1495#	1485#	1250	741
Highest/Lowest	1:0.49	1:0.68	1:0.69	1:0.77	1:0.89	1:0.96	1:0.93	1:0.98	1:0.95

#, * Indicate the highest and lowest phosphine concentrations, respectively, measured each time.

表六　空倉施磷化鋁0.969 kg a.i./倉於地面或倉頂後，倉內磷化氫之濃度(ppm)分布

Table 6. Concentration of phosphine at various times after aluminum phosphate application at 0.969 kg a.i./silo to the empty silos

Depth (m)	Concentration (ppm) of PH_3 at various times (h) after AlP applied					
	24	48	72	96	120	144
Aluminum phosphate placed at the bottom						
Center						
0	68	73	60	48	39	21
3	58*	71	56	42*	28*	18*
6	62	74	57	46	37	20
9	63	76	60	47	38	21
12	63	76	58	48	37	20
Circumference						
0	63	73	59	45	37	19
3	61	71	45*	46	36	21
6	64	70*	50	47	37	20
9	70	81	60	48	39	22
12	70#	82#	60#	48#	39#	22#
Highest/Lowest	1:0.87	1:0.92	1:0.75	1:0.88	1:0.71	1:0.82
Aluminum phosphate placed at the top						
Circumference						
0	63	62	48#	22*	22*	9*
3	60	62	44	41	28	13
6	78	68#	39	37	43#	14
9	78#	54	45	32	35	16#
12	55*	47*	38*	49#	24	12
Highest/Lowest	1:0.71	1:0.69	1:0.79	1:0.65	1:0.51	1:0.56

#, * Indicate the highest and lowest phosphine concentrations, respectively, measured each time.

增為 1:0.14。而沒有氣體循環之高粱倉(表四)，在施藥後 24～120 h，磷化氫氣體之最高與最低濃度比為 1:0.11 以下。

有氣體循環之玉米倉，施用磷化鋁 9.69 kg a.i./倉於積穀表面，磷化氫在倉內各處分佈如表二。施藥後 24 h，磷化氫之濃度最高，達到 1246 ppm，最低濃度為 1024 ppm。最高與最低之濃度比為 1:0.82。施藥後 28 h，各測氣點之磷化氫濃度都下降。磷化氫氣體最高與最低之濃度比為 1:081 至 1:0.96，即最低濃度為最高濃度之 81～96%。同樣有氣體循環之玉米倉，當磷化鋁使用量減少為 5.814 kg a.i./倉時(表三)，在 96 h 以內，倉內各點之磷化氫濃氣體最高與最低之濃度比為 1:0.86 至 1:0.92。使用氣體循環之高粱倉(表五)，施藥後 24～72 h，倉內磷化氫濃氣體最高與最低之濃度比均維持 1:0.89 至 1:0.98。

由以上兩組資料顯示，容量相同但沒有氣體循環之倉庫，不論儲藏玉米或高粱，施用磷化鋁後所產生之磷化氫，僅靠重力向下擴散。因受到儲穀之阻礙，擴散速度緩慢，且不均勻。同一次測得磷化氫氣體最高與最低濃度比為 1:0.14 以下，即每次磷化氫之最低濃度僅為最高之 14% 以下；有氣體循環時，磷化氫氣體最高與最低之濃度比為 1:0.81 以上，即磷化氫之最低濃度為最高之 81% 以上。空倉時(表六)，無儲穀阻礙，磷化氫垂直擴散迅速，氣體最高與最低之濃度比為

表七　預置於氣體循環倉積穀表面之玉米象及擬穀盜成蟲經燻蒸後之死亡率(%)

Table 7. Mortality (%) of insects placed on the surface of grain after fumigation in the silo with a circulatory system

Dose (AlP kg a.i./silo)	*Sitohphilus zaemais*	*Tribolium castaneum*
Corn silo		
9.69	100	100
5.81	100	100
Control	3.8	9.2
Sorghum silo		
9.69	100	100
Control	12.4	4.4

表八　有氣體循環之玉米倉經磷化鋁(9.69 kg a.i./倉)燻蒸後，積穀表面之害蟲密度(活蟲數/公升穀樣)。

Table 8. Number of live insects obtained per liter of corn sample after fumigation at 9.69 kg a.i./silo with a circulatory system

Time (days) after fumigation	*Rhyzopertha dominica*	*Tribolium castaneum*	*Sitophilus zaemais*	*Cryptolestes ferrugineus*	*Oryzaephilussu rinamensis*
Fumigation					
0*	0	0	0	0	0
10	0	0	0	0	0
42	0	0	1.1	0	0
Control					
0*	0	0	0	0.2	0
10	0	0	0	1.2	0
42	0.1	0	10.5	1.3	0

*The day before fumigation.

表九　有氣體循環之高粱倉經磷化鋁(9.69 kg a.i./倉)燻蒸後，積穀表面之害蟲密度(活蟲數/公升穀樣)。

Table 9. Number of live insects obtained per liter of sorghum sample after fumigation at 9.69 kg a.i./silo with a circulatory system

Time (days) after fumigation	*Rhyzopertha dominica*	*Tribolium castaneum*	*Sitophilus zaemais*	*Cryptolestes ferrugineus*	*Oryzaephilus surinamensis*
Fumigation					
0*	0.8	0.6	0.6	1.0	0.6
20	0	0	0	0.2	0
Control					
0*	1.1	2.3	11.8	19.2	4.9
20	0.8	0.1	4.5	45.3	8.8

*The day before fumigation.

1:0.70以上。

Sinha等(1967)以小型倉庫，內儲小麥6 ft深，好達勝(phostoxin)施於積穀表面下3 in或2.5 ft，結果測得4 ft深之磷化氫濃度最高。Halliday and Kazaure (1968)在花生倉以好達勝燻蒸時，亦發現倉內各點之磷化氫濃度並不相同。Peng (1980) 曾利用高4.1 m鐵質圓筒作模型試驗，磷化鋁施用於稻穀之積穀表面。雖然磷化氫較空氣重1.2倍，在24 h，磷化氫氣體尚未到達4 m之深度。至48 h，4 m處之磷化氫濃度僅為施藥處之8.8%。由以上文獻報導，可知磷化氫之分佈或穿透性，確實受到燻蒸物品之阻礙，而未能呈均勻之分散。但Lin *et al.* (1966)報導進口小麥，以輸送帶送入圓筒倉時，從倉頂定時均勻投燻蒸劑，而在5、12及19 m處測定磷化氫之濃度並無差別。

Berck (1968)將燻蒸後之穀物以氮氣沖洗，回收磷化氫，發現有穀物者，磷化氫回收量顯著減少。他認為這是由於磷化氫被穀物吸收所致。Sittisuang and Nakakita (1985)報導玉米及稻穀會吸收磷化氫，而且玉米吸收量較稻穀為大。磷化氫被吸收而濃度降低。由表一至表五之資料顯示，不論玉米或高粱倉，燻蒸後120小時之磷化氫濃度，僅有24 h之3.5%，或以下；而空倉時(表六)，仍有30%。磷化氫被吸收量則因穀物之種類、數量、形態、水份含量、燻蒸劑用量、處理時間、空氣濕度等而異(Lindgren and Vincent, 1959; Vincent and Lindgren, 1971)。穀物經燻蒸及適當之通風後，氣態之燻蒸劑容易揮發，減少殘留。以磷化氫為例，會逐步氧化成低毒之磷酸(Dhaliwal, 1974)。

預置於使用氣體循環裝置之玉米倉及高粱倉積穀表面之玉米象及擬穀盜等供試昆蟲，經燻蒸後，死亡率皆達100% (表七)。而在玉米對照倉者，則僅有3.8及9.2%之死亡率；高粱對照倉，則有12.4及4.4%之死亡率。至於玉米倉積穀表面之穀樣(表8)，經燻蒸後10日，並無活蟲記錄。第42日之樣品中，象鼻蟲平均仍有1.1隻成活。使用氣體循環裝置之高粱倉(表九)，燻蒸後20日，高粱中之昆蟲死亡率幾達100%，但仍有角胸粉扁蟲(0.2隻/公升)成活。稻穀倉庫經燻蒸後也有害蟲再發生的記錄(Ko, 1989)。國外有許多儲物害蟲對磷化氫已有抗藥性報導(Monro *et. al.*, 1972; Kem, 1975; Bell, 1976; Bell *et. al.*, 1977; Nakakita and Winks, 1981; Nakakita *et al.*, 1985; Nakakita and Kuroda, 1986; Zettler *et. al.*, 1989; Zettler and Keever, 1994)，而國內害蟲是否以已有抗藥性，

正試驗中。

此外，穀層深處或底層之昆蟲相，須利用真空式取樣機取樣，才能瞭解。此種取樣機雖可分解，進入穀倉後再組合，但在此種鐵質圓筒倉之積穀表面至倉頂之空間有限，取樣機難以操作。因此，深層穀樣難以取得。

誌　謝

本研究承行政院農業委會84農建-3.2-糧-24及85農建-3.3-糧-01經費資助；嘉義縣義竹鄉農會提供試驗穀物及倉庫；嘉怡股份有限公司協助裝設氣體循環系統；初稿承臺灣省農業藥物毒物試驗所高主任穗生博士，國立自然科學博物館謝副館長豐國博士，及兩位中華昆蟲審稿專家斧正；謹誌謝忱。

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收件日期：1999年3月26日
接受日期：1999年4月28日

Vertical Penetration and Distribution of Phosphine in Corn and Sorghum Stored in Steel Silos

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ABSTRACT

Silos of 10.55 m in diameter and 12 m in height were made of corrugated circular steel for corn or sorghum storage. Some were equipped with circulatory systems consisting of a plastic pipe 10.16 cm (4 in) in diameter from the top to the bottom. Before loading, two sets of gas sampling lines, 4 mm in diameter, containing five lines each, were installed in the center and on the circumference of the silo. The openings in each set were at depths of 0, 3, 6, 9 and 12 m. The gas samples were measured using an EC80 phosphine monitor every 24 h after fumigant application. Phosphine was generated by Detia bag blankets containing 57.6% aluminum phosphate placed on the surface of the grain mass. Generally, the highest concentration of phosphine was obtained 24 h after application in each silo. In silos without a circulatory system, phosphine penetrated down to the bottom through interstitial spaces in the corn or sorghum column. The concentration at the surface, where application was made, was the highest at 24 h. The concentration dropped thereafter due to diffusion, adsorption and decomposition. The deeper into the column, the lower the phosphine concentration was. In each measurement during 24～120 h after fumigant application, the ratios of the highest to lowest phosphine concentration was between 1:0.02 and 1:0.14, i.e., the lowest phosphine concentration was only 2～14% of the highest. In silos with a circulatory system, phosphine was sucked into an aeration pipe from the top and sent to the bottom of the silo, then moved upwards through the grain mass. During 24～120 h after fumigant application, the ratios of the highest to lowest phosphine concentration was within 1:0.81 and 1:0.98, i.e., the lowest concentration was 81～98% of the highest. In the circulatory silo, mortality rates for test insects placed on the surface of grain or insects obtained from grain samples showed 100% control.

Key words: steel silo, phosphine, vertical penetration and distribution, corn, sorghum

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