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Functional Mechanisms of Greenfeed "Daliwan" Fertilizer

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Abstract

Greenfeed compound fertilizer, commercial name in China "Daliwan", originated from Malaysia, is a slow release fertilizer based on aluminosilicate as carrier. In China's application since 2016, "Daliwan" performed excellent in vegetables and fruit trees and gained much positive feedbacks from farmers. Basically, field performances observed included broader and flattened leaves, glossy texture on leaves, early budding, high fruit setting, even on fruit development and longer in shelf-life. In past research, we concluded these performances based on the fertilizer characteristics such as ion gradient activity, pH balancer and also water holding ability. In this report, we further concluded more on these mechanisms based on observation from different parts of crops. The main mechanisms we further summarized here were: root zone effect; ammonium nitrogen being supplied to avoid crops energy consumption on metabolism; induction of dissolution of unavailable phosphate ion. In leave performance, it is concluded to increase the assimilation of ammonium ion and the content of chlorophyll; inhibition of harmful effect of heavy metal to electron transport chain; and lastly, the increase on leaves photosynthesis rate by silica ion.

Keywords

Compound Fertilizer, Greenfeed Agro, Aluminosilicate, Daliwan, Sustainable Development

马来西亚绿丰复合肥“大力丸”产品作用机理

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摘 要

马来西亚绿丰公司复合肥“大力丸”，是一款以沸石硅铝酸盐为载体的新型缓释肥料。在各类经作包括蔬菜、果树的使用得到农户的认可。主要田间观察表现为叶片平展、具有光泽度、叶花芽提早、座果率高、果实发育良好、产品贮架期长等效果。本单位曾以肥料本身的特性如具有离子梯度、pH平衡者和持效水分长等因素，总结产品特性。在本篇报告中，将细化产品在根和树体发挥作用的所观察到的效果，结合现有科学文献所总结到的结果，并以本产品在各作物表现的数据，进一步综合归纳产品发挥作用的理论基础。从几个方面可归纳总结：在根系增加根际效益；根部吸收铵离子有助减少作物总体能量耗损；另外可诱导离子交换性磷的再利用。在叶片的表现，可提升铵态氮的同化能力，增加叶绿素含量；减少重金属对电子传递链的破坏；以及硅离子增加叶表光合速率能力等六大方面。

关键词

复合肥，绿丰农业，硅铝酸盐，大力丸，可持续发展

1. 引言

沸石主要由铝和硅等元素组成的硅铝酸盐，此具有正四面立体结构的化合物带有很多孔隙，也赋予了沸石高吸附能力[1] [2]。由于沸石空腔内多带有负电荷，因此这些界面，依铝和硅替代程度的不同，具有不同程度的阳离子交换能力。目前报导，其对阳离子的选择性从高到低依次为 Cs > Rb > K > NH_4 > Ba > Sr > Na > Ca > Fe > Al > Mg > Li [3]，Pb > NH_4 > Cu，Cd > Zn，Co > Ni > Hg [4]。天然斜发沸石(clinoptilolite)为天然存在量最丰富的沸石矿种，目前其应用的领域包括工业、农业、生态、医药等[5] [6]。在农业上，由于其特有的硅铝酸盐结构，它在增添到化肥当中后具有保肥增效的作用。在研究上，它对减少大量元素随水流失的效果极为显著[7]，也在促产增收上有大幅的帮助[8]。沸石的多孔隙结构，可吸附其自身重量 60%的水分，此水分可自由进出其立体三维结构，不影响架构组成[9]。因此，在农田水分管理上，沸石资材是一个能抗旱的材料，它的吸附性能让土壤更快速的湿润，并改善水分在土壤的横向分布，有助于根圈对水分的行用效率增加。沸石中的硅元素是作物硅的重要天然来源。作物对于硅的利用可透过主动和被动运输来完成[10] [11] [12] [13] [14]。Ma 等人认为，硅的吸收靠的是侧根而非根毛。当进入木质部后，硅多被运送至茎部，主要途径是蒸散作用[15]，因此，作物体内的硅浓度大小直接反应了作物的蒸散速率[16]。一般在老叶累积较新幼叶多，在细胞壁上形成一种植硅体(phytoliths)或称为硅体的结构。

马来西亚绿丰公司产品“大力丸”，为使用沸石硅铝酸盐为载体的新型缓释肥料。在 2016 年进入中国市场，主要配方为氮磷钾镁 20-15-10-2 和 12-12-20-2，另含有中微量元素钙、硼、硫、铁、锰、锌、硅等。绿丰“大力丸”肥料主要针对春肥、膨果期和采摘后肥三个用肥时期，具体根据果农的施肥习惯使用。按挂果量和树龄大小，每棵大型果树使用 16~40 粒不等。建议用法为穴施(图 1)，于根冠滴水线下

每株大树取 4 个穴，将建议用量埋入 15~20 公分处。在众多田间实践工作当中，其省工省力的效益，尤其是山区果树已为广大老百姓所接受。引进中国当时，为药肥双减政策启动时期，经由 2 年多在华销售，应用在诸多作物，除了省肥的功效外，对于作物提质增效的效益也十分突出[17] [18] [19] [20]，也同时符合了国家减肥增效的需求。在前面的研究当中，本肥料曾就肥料本身的特性如离子梯度、pH 平衡者和持效水分长等因素分析过产品机理[21]。本篇报告中，将细化产品在作物部位发挥作用的机理，并以本产品在各作物表现的数据，进一步综合总结产品发挥作用的理论基础。

Figure 1. Corn root status with "Daliwan" fertilizer (blue arrow)
图 1. 使用"大力丸"玉米在采收后观察其根和"大力丸"(蓝色箭头)分布情况

2. 根际效益

根际施肥，也称为根圈施肥，最直观的做法是在土面下 10~50 公分处，以条施、点施，或将肥料放入后覆土的做法。自 1970 年代开始迄今，一直都有不少研究认为根际施肥优于土表撒施[22]-[28]。在田间操作，土表撒施的问题十分显而易见，肥料除了土表随温度和水分流失的问题之外，更有造成根系上浮乃至树体不抗寒冻等问题。Borges 和 Mallarino 等人研究，相较于土表撒施，土面下施肥可增加作物对磷和钾的吸收[29]，更有研究表明土面下的施肥方法和提产、增收有很大的关系[30] [31] [32]。

3. 沸石增加了根部吸收铵离子，减少作物总体能量耗损

作物偏好吸收的无机盐氮素分别为硝酸态(NO_3^-)和铵态氮(NH_4^+)，而铵态氮是作物较为喜欢被利用的型态。但在通气性较好的土壤中，由于铵态氮的硝化作用和挥发的作用，其浓度往往只有硝态氮的 10~1000 之 1 的含量[33]。在土壤中，硝酸根离子须经由还原成亚硝根离子(式 1)，最后还原为铵态离子(式 2)，才能被作物吸收：

$$NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + 2H_2O \tag{1}$$

$$NO_2^- + 8H^+ + 6e^- \rightarrow NH_4^+ + 2H_2O \quad (2)$$

相较于直接同化利用铵态离子，此系列的还原作用消耗了作物总能量的 15%以上，反之，直接同化铵离子的总耗能只有 2%~5% [33] [34]。前人研究，沸石对于铵态氮的阳离子交换力高达 67.51%~79.5% [2] [3] [4]。在 Huang 和 Petrovic 于水稻的研究报告中，应用了含沸石的肥料，作物对氮的利用效率提高了 16%~22% [35]，更少的硝态氮需经由还原过程消耗作物能量，因此作物保有更多能量来进行其他生理活动[36]。综上，大力丸在土壤中发挥的效益，即在于吸附了更多的铵态氮素，直接供作物同化作用，减少作物整体能量的消耗。

4. 诱导离子交换性磷的再被利用

在土壤中，磷素易被金属氢氧化物结合形成无效性磷。沸石经由改善土壤的 pH (降低酸化)、增加铝和铁元素和其他碱金属和负电离子的土壤离子交换量，来增进磷的有效性。在沸石的存在下，元素诸如钙离子易于被交换给作物利用，此时，为了平衡沸石的电价，土壤中的磷酸盐会被加速溶出，以平衡沸石“耗损”的钙离子[37] [38]。在有硅的作用下，磷在土壤的有效性可以提高 50% [39]，但也有报告指出，过度的使用硅，将在根的内表皮细胞产生沉积，导致原生质联丝的障碍，让磷的传送效率降低[15]。

5. 铵态氮同化提升，增加叶绿素含量

铵态氮在根部的吸收同化，运输至叶片时，在由谷氨酰胺合成酶的作用下转化为谷氨酰胺，谷氨酰胺进一步转化形成谷氨酸，谷氨酸是叶绿素生合成的主要原料[34]。在十字花科的球茎甘蓝当中，提高了铵态氮处理，相较于只供应硝态氮，其叶绿素含量提升了 21%，净光合作用的表现也有所上升。在石蒜科的晚香玉上，使用含沸石的肥料也让其叶片的叶绿素含量增加 22.7% [40]。此数据可对应绿丰公司在不同作物的叶绿素增加的百分比为 6.69%~18.46% (表 1) [40]。值得一提的是，表 1 中已发表的作物叶绿素的增加幅度为 4.4%~108.3%，数据均为作物在逆境情况下所测。显示如“大力丸”在逆境情况下叶绿素含量可能有类似更高的表现。在表 2 当中，受到不同逆境的作物的叶绿素 a，b 都有增加。叶绿素 a 为光合反应的主色素，而叶绿素 b 为辅助色素，其中西红柿、小麦的叶绿素 a 的增幅均高于 b。

Table 1. Chlorophyll increase rate of different crops using silica-containing fertilizer
表 1. 使用含硅复合肥不同作物总叶绿素增加百分比

作物	逆境	总叶绿素增加百分比(%)	参考出处
玉米	常态	11.9	[58]
水稻	干旱	19.4	[59]
西红柿	干旱	71.4	[60]
大麦	重金属	45.2	[61]
棉花	重金属	59.3	[62]
黄瓜	重金属	108.3	[63]
绿豆	重金属	33.0	[64]
小麦	重金属	4.4-50	[65] [66]
草坪	盐分	81.8	[67]
油棕	常态	6.69	[41]
香蕉	常态	13.14	[41]
胡椒	常态	18.00	[41]
橡胶	常态	7.20	[41]
芒果	常态	10.40	[41]
草花	常态	18.46	[41]

Table 2. Chlorophyll a, b increase rate of different crops using silica-containing fertilizer
表 2. 使用含硅复合肥不同作物叶绿素 a, b 增加百分比

作物	逆境	叶绿素含量%		参考出处
		叶绿素 a	叶绿素 b	
西红柿	干旱	80.0	71.4	[60]
黄瓜	重金属	133.3	162.5	[63]
小麦	重金属	36.8	50	[65] [66]
草坪	盐分	82.8	79.6	[67]
小麦	盐分	22.4	2.8	[68]
小麦	盐分	49.4	44.0	[68]
西红柿	盐分	16.4	13.3	[69]

6. 硅元素减少电子传递链被重属抑制失活

电子传递链也称为光合磷酸化反应，光合反应系统对于金属离子十分敏感[42]。金属离子尤其对光反应 II 中的受体具有高抑制性[43] [44] [45]。在土壤中，单硅酸于土壤常不太活动[46]，因此它们通常会与重金属或有机质形成胶体[47]。沸石具有可交换的钠、钙和钾等离子，使得它们可和镉、铅、锰、锌等离子作交换[48] [49]，直接减少了它们对光合系统的抑制。在作物体内，硅元素形成的多硅酸也可以扮演其在土壤中的角色，免除作物受到重金属离子的胁迫[50] (图 2)。

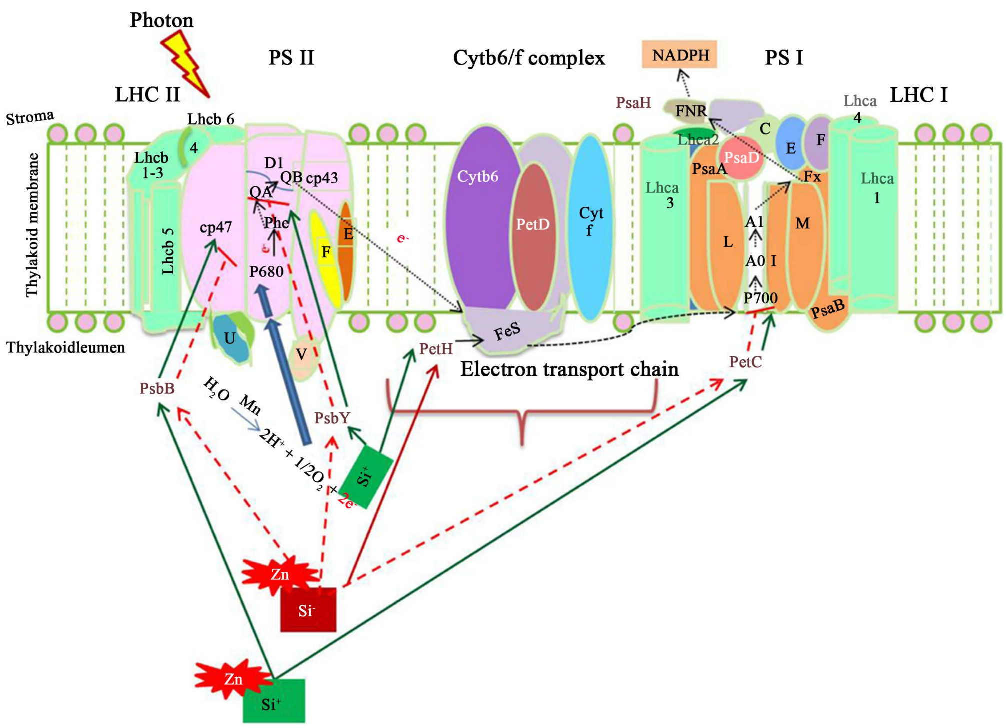

Figure 2. Photosynthesis model indicates silica binding on Zn and its prevention of Zn to bind with photosynthesis receptor. PSII photosynthesis system II; Cytb6f: cytochrome b6/f protein; PSI: photosynthesis system I; LHCI: Light harvest cytochrome I [71] [72] [73]
图 2. 光合系统模型示意硅元素可和锌元素结合，减少锌元素和光合系统中的受体结合，影响光合反应。PSII：光合系统 II；Cytb6f：色素 b6/f 蛋白；PSI：光合系统 I；LHCI：光接收蛋白 I [71] [72] [73]

7. 硅元素增加叶表光合速率能力

植硅体是高等植物吸取可溶性二氧化硅后，沉淀于植物细胞内或细胞外部的含水非晶态二氧化硅颗粒。植硅体在叶片上也产生了更佳的蜡防护层，对叶片形成了更佳的保护[51]。此现象可在“大力丸”产品于各个作物的叶片表现上看出(图 3)。植硅体的主要存在于叶片表皮细胞，增加了细胞壁的机械性力量，增加纤维素的长度[52]。在 Liu 的研究，植硅体在细胞壁会形成有机硅化物，可和金属如铝、锰、镉等结合[53]，防止作物的吸收，减少重金属的危害[54] [55]。此外，Quanzhi 和 Erming 的研究中指出，硅对叶片面积的增大有明显的作用(表 3、图 4)，此对截取更多的阳光，提升光合速率有相关性[56]。表 4 中，使用绿丰“大力丸”产品的光合速率提升达 12.9%~28.2%。Inanaga 也报导使用了含硅肥料，会减少上位叶对下位叶造成的遮荫，因此有更多的叶面积能接收阳光，提高叶片光合作用[57]。

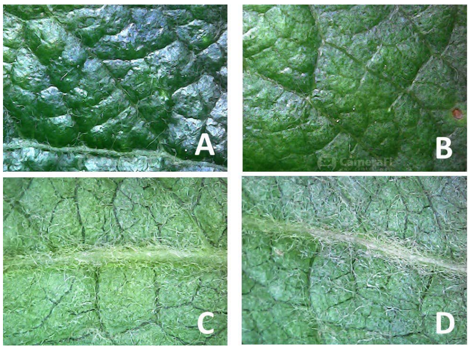

Figure 3. Apple using Greenfeed ((A), (C)) and common fertilizer ((B), (D)) under 300× microscopic observation on leave. (A): Front leaf with glossy-look of cuticle; (B): common fertilizer; (C): Back leaf with coarse surface; (D): common fertilizer
图 3. 使用绿丰“大力丸”苹果叶片((A), (C))和常规肥料((B), (D))于 300 倍显微镜下观察。(A) 叶片正面角质层明显，具有光泽；(B) 常规肥料；(C) 叶背面叶脉较粗；(D) 常规肥料

Table 3. Leaves size (cm) investigation after 77 days applied “Daliwan”
表 3. 春施肥使用“大力丸”77 天后调查叶片大小(cm)

	大力丸叶长	常规肥叶长	大力丸叶宽	常规肥叶宽
1	81	66	57	50
2	73	74	50	45
3	80	75	54	50
4	85	83	55	52
5	83	62	59	46
6	85	72	60	53
7	76	75	51	46
8	75	77	55	52
9	77	70	55	50
10	78	64	50	50
平均	79.3	71.8	54.6	49.4
标准偏差	4.19	6.43	3.50	2.8
高出百分比	9.46%	-	9.52%	-

Figure 4. Apple leaves applied Greenfeed "Daliwan" and common fertilizer after 77 day
图 4. 春施肥使用"大力丸"77 天后调查苹果叶片大小

Table 4. Photosynthesis rate increase rate of different crops using silica-containing fertilizer
表 4. 使用含硅复合肥不同作物光合作用增加百分比

作物	逆境	光合速率增加百分比%	参考出处
玉米	常态	24.9	[58]
高粱	干旱	130.8	[70]
大麦	重金属	76.2	[61]
棉花	重金属	90.2	[62]
油棕	常态	12.93	[41]
香蕉	常态	13.81	[41]
胡椒	常态	19.1	[41]
橡胶	常态	28.21	[41]
芒果	常态	20.47	[41]

8. 总结

马来西亚绿丰公司复合肥"大力丸"在数千个使用案例的反馈表现，除了其缓释性和省工省肥特性之外，还有复合肥当中的中微量元素，在元素营养配方上提供了一站式的供给。综上归纳点，前人研究和我司于田间走访的反馈，可相互对应，在复合肥方面的节肥、增效上具有高应用推广价值。

致　谢

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