ID China bio-gas experimentations
法国发起发展组织昆明办公室“沼气池优化管理”
及“沼渣沼液多用途”系列研究

USING BIO-SLURRY FOR FERTILISATION
沼渣沼液施肥功效研究

Report - December 2013 报告时间：2013 年 12 月

Nicolas Borchers, ID China Agriculture Officer[1]

Table of Contents

[1] n.borchers@id-ong.org

1 ABSTRACT 摘要

As part of its commitment to provide continuous support to the more than 2500 families using a biogas digester build by Initiative Développement (ID), the NGO has engaged in a one year study focused on optimising the management of biogas digesters, as well as researching the various uses of the bio-slurry.

In particular, ID has researched how the bio-slurry could be used by the households as a fertiliser. Three families were recruited amongst ID biogas beneficiaries in Zhaotong 昭通 prefecture, Yunnan 云南 province, China, and made a plot available for field trials. On one plot and two orchards in Lianhe 联合village, Sayu 洒渔township, experiments were made on intercropped **corn** and **potato** as well as **apple tree**, while on another plot in Zhongying 中营 village, Xiaolongdong 小龙洞 township, an experiment was made on **tobacco**. Besides, two other experiments were started with the same households on apple orchards and corn, but were abandoned due to technical difficulties. The bio-slurry was sourced from the water chamber of the beneficiaries' $10m^3$ fixed-dome biogas digesters ("Chinese model"). The experiments were held between March and September 2013.

The corn and potato field was divided in three sections. In two sections, liquid bio-slurry was used while planting the crop, alongside manure and mineral fertilisers. On the third section ("conventional") only the two latter were used. Urea, manure and bio-slurry were applied directly in the planting hole, according to the usage in the region, however superphosphate and sulphate of potash were either supplied in the planting hole or top-dressed. The quantities of mineral fertilisers were different on each group.

On corn, differences in germination rates indicate that high amounts of urea might be detrimental to germination. Furthermore, on the two bio-slurry groups, the growth was delayed, and the final height of the crop was significantly lower by 14% and 8% respectively, while the final yield was significantly lower (-40% and -26%, respectively), compared to the conventional group (significance level: 5%).

On potato, the germination rate was lower on the bio-slurry groups (92% and 86% respectively, compared to 100%, or complete emergence, on group 3). If P and K were top-dressed in group 1, the emergence rate was 82%. On the two bio-slurry groups the growth was delayed, but the final yields were not significantly different.

These results advocate against the use of liquid bio-slurry at planting time on corn and potato. The bio-slurry should better be used once the crop has emerged and strengthened. This could be confirmed by conducting specific trials.

The tobacco field was divided in two sections. Both groups received the same quantity of manure and mineral fertilisers. In addiction, on group 1 liquid bio-slurry was applied once in soil application at two weeks after transplanting, and once in leaf spraying at 8 weeks.

The leaves of the bio-slurry group presented a darker green colour than the non bio-slurry group, but neither the height of the crop nor the size of the leaves were significantly different. A sample from the harvest (second priming) was examined. The leaves in the bio-slurry group were found to be of a lower quality once cured.

On tobacco, bio-slurry thus appears effective in providing nitrogen to the crop. Whether the soil or the foliar application was more effective was not established. However, this excess in nitrogen was detrimental to the proper curing. Therefore it may be advised, if using bio-slurry, to reduce the quantity of the other fertilisers accordingly.

The two apple orchards were divided in three groups. On two groups, liquid bio-slurry was used once in soil application at blooming time, and used in spray on the leaves throughout the season. Terminal shoot growth and apple size were monitored quantitatively. No statistically significant difference was found between the different groups. Qualitatively, one farmer reported slightly lusher leaves on the bio-slurry groups and a slightly improved taste of the apples, but the differences were not obvious. The yield per tree did not seem affected.

法国发起发展组织 Initiative Développement (以下简称 ID) 为 2500 余户农村家庭建设了户用沼气池，为了向受益者提供持续的项目后期维护，ID 进行了为期一年的"沼气池优化管理"和"沼渣沼液多种用途"研究。

ID 尤其针对农户可以如何利用沼渣沼液进行施肥做了研究。我们在 ID 户用沼气池项目实施地云南省昭通市，从受益者中选择了三家自愿协助试验的农户，并确定了试验地块：1. 在洒渔乡联合村的一块玉米、土豆、和苹果的间作地里进行试验，2. 在小龙洞乡中营村的一块烟叶地里进行试验。除此之外，我们还进行了两个在相同农户协助下的苹果园和玉米地里的试验，但因为技术上的困难，试验没有完成。沼渣沼液来自于协助试验的农户的 10 立方米的固顶式沼气池。试验时间为 2013 年 3 月至 9 月。

玉米田和土豆田被分为三块。其中两块，在育苗期给作物施沼液、粪肥、和化肥，第三块田遵循传统做法，只给作物施粪肥和化肥。施尿素、粪肥、和沼液时，基于该地区的普遍做法，进行穴施。施加过磷酸钙和硫酸钾肥时进行穴施或给表肥。每组田所施的化肥量不同。

玉米田的试验结果显示，大量施用尿素不利于玉米出苗。此外，与用传统方法施肥的地块相较，两个施用了沼液的地块上，玉米长势放缓，玉米成熟后的高度分别降低了 14% 和 8% ，同时，产量也分别大幅减少了 40% 和 26%, 作物的收成差异显著性程度达到 5%

土豆田的试验结果显示，用传统方法施肥的地块上，土豆的出苗率为 100% （全部出苗），在两个施用了沼液的地块上，土豆的出苗率分别为 92% 和 86%, 如果在施沼液的地块上施磷钾肥作表肥，那么出苗率在 82%, 土豆在两块施了沼液的地块上长势放缓，但最终的产量没有受到显著影响。

由此，不提倡在玉米和土豆的育苗期施用沼液，应在其出苗并长势稳定后再施用。相应试验可以证明。

烟叶田被分为两个地块，并分别施用了等量的粪肥和化肥，其中一个地块在烟叶苗移栽两周后施用了一次沼液，并在第八周用沼液进行叶面施肥。

施用过沼液的烟叶，叶片颜色呈墨绿色，而植株高度和叶片大小没有显著差异。其次，我们检测了收成样本，施用过沼液的烟叶品质更低。

烟叶田的试验结果表明，沼液能够有效地为植株提供氮。至于是土壤施肥还是叶面施肥更有效尚不确定。然而，过量的氮不利于植株的生长。因此，在施用沼液时应减少其他肥料的用量。

两个苹果园被分为三组。其中两组在果树开花期用沼液施土壤肥，并在整个开花期用沼液进行叶面施肥。

定量监测苹果树的枝条生长和果实大小。各组样本在监测数据结果上没有明显差异。一位村民反映，施用过沼液的果树枝叶稍加茂盛，果实的口味也稍有改善，但差异并不显著。每棵植株的苹果产量也未受到影响。

2 RATIONALE

"Bio-slurry" is the residue of the fermentation of biomass in a biogas digester. The bio-slurry is rich in various mineral and organic elements that renders it useful for a variety of agricultural uses including plant fertilisation, as a natural pesticide, or for pre-soaking seeds. These uses are widely promoted by development organisations and governmental agencies throughout the world. In China in particular, the government publishes training material on how to use the bio-slurry.

As part of its continued support, ID China is giving regular training courses and advices to the beneficiaries of its biogas programs. Amongst others, the proper use of bio-slurry is taught. However, most of the knowledge and material used by ID China is coming from second-hand sources. Hence, ID China has launched a project of terrain experimentation to gain a direct and in-depth understanding of the use of bio-slurry for agriculture.

The principle behind this project is to involve ID China in partnership with beneficiaries into real-life, terrain-oriented experimentations. The beneficiary provides a field for the trials, which he manages according to a protocol agreed between ID China and himself, while ID China is responsible for the regular qualitative and quantitative monitoring. The goal of the experiment is not only to confirm the validity of the scientific knowledge on the terrain, but also to bring the beneficiary to judge the results by himself. If positive and tangible results are achieved, the beneficiary is motivated to adopt the new and beneficial technique, and becomes a hinge for the spread of the new knowledge within the local community.

Furthermore, once the potential uses of bio-slurry have been highlighted, what would otherwise only have been a by-product of biogas production can acquire a new/higher value in the eyes of the beneficiaries. This value acts as a secondary motivation, or co-advantage, in the use of the bio-digester. Developing the use of bio-slurry can therefore contribute to the long-term success of a rural biogas program.

Specifically, the experiments described below aimed at the following goals:

- experimenting the use of several fertilisation plans on corn, potato, tobacco and apple trees, some plans including bio-slurry and others not
- evaluate the impact of these fertilisation plans on the crop germination, growth, yield, and general fertility
- observe any potential counter-effects of bio-slurry
- research the most practical method of transporting and applying bio-slurry on the field

3 METHOD

3.1 Recruiting farmers and selecting the plots

In the summer of 2012, about 35 surveys were carried out amongst the beneficiaries of ID China's biogas programs to find out about the households' agricultural practises and their use of the bio-slurry. According to these surveys, it was established that the main crops grown locally, on which bio-slurry could be used for fertilisation, were corn, potato, tobacco, apple trees, cherry trees and radish. Minor surfaces of rice, beans, cabbage and other fruit trees were also planted. Corn and potato are usually found intercropped together. It was decided to carry out the fertilisation experimentations on corn, potato, tobacco, and apple tree.

Beneficiaries were recruited amongst the 2500 biogas households which built a digester with the help of ID China since 2008 in Zhaotong 昭通, Yunnan province, China. The criteria for selecting the households included being able to provide a small field for the trials, and having a bio-digester currently in use. Furthermore, a genuine motivation, sense of responsibility and reliability were sought from the households participating in the experiment. The household were not remunerated, although a few small gifts were brought, such as biogas spare parts or fresh fruits/vegetables. An insurance mechanism was agreed in case of loss of harvest (more details below).

According to these criteria, three households were recruited in autumn 2012 (table 1). The fields and orchards on which to carry out the experiments were selected for their homogeneity (soil, slope, sun, tree varieties).

Name of responsible person	Township	Village	Crop(s)	Surface of plot 亩 (mu)	Number of trees
Ben 1	洒渔 (Sayu)	联合 (Lianhe)	Apple (Fuji)	1.4	50
			Corn/potato (intercropped)	0.6	
Ben 2	洒渔 (Sayu)	联合 (Lianhe)	Apple (Fuji)	1.4	77
			Corn	0.6	
Ben 3	小龙洞 (Xiaolongdong)	中营 (Zhongying)	Tobacco	0.8	

Table 1: List of households participating in the experiments

3.2 Experimental groups – table of treatments

3.2.1 Corn and potato

As described in table 1, one field was planted with corn only and another with intercropped corn and potato. On these two fields, the following fertilisation formulations were tested. The exact quantities are given in the “results” section.

Group 1	Compost Mineral fertilisers (high amount) Bio-slurry (at planting)
Group 2	Compost Mineral fertilisers (low amount) Bio-slurry (at planting)
Group 3	According to the farmer's usual habit, no use of bio-slurry

Table 2: Treatments on corn and potato

3.2.2 Tobacco

Two groups were made, corresponding to the treatments used for another experiment on pest control (see the document “Using bio-slurry for pest control”). The treatments are indicated in table 3. No control group was established.

	Soil	**Foliar**
Group 1	Compost Mineral fertilisers Bio-slurry (top-dressed)	Pesticides Bio-slurry (1 time)
Group 2	Compost Mineral fertilisers	Pesticides

Table 3: Treatments for tobacco

3.2.3 Apple

Three groups were made, corresponding to the treatments used for another experiment on pest control (see the document "Using bio-slurry for pest control"). The treatments are indicated in table 4.

	Soil	**Foliar**
Group 1	Compost Mineral fertilisers Bio-slurry	Pesticides Bio-slurry
Group 2	Compost Mineral fertilisers Bio-slurry	Pesticides Bio-slurry
Group 3	Compost Mineral fertilisers	Pesticides

Table 4: Treatments for apple trees

3.3 Role of the beneficiaries

The work and management on the orchards and fields were entirely left to the beneficiaries. This included tilling, planting, fertilisation, spraying of bio-slurry and/or pesticide, pruning, and harvest. On the plots on which the "farmer's management" was experimented, the beneficiaries were responsible for choosing themselves the fertilisers, their quantity and application methods.

The staff of ID China was present during each major step to monitor precisely the operations. The products used, their quantities and their application methods were written down. Quantities were weighed when necessary.

In particular, the initial fertilisation of the corn and potato plots were done under ID's supervision, since ID provided the fertilisers and instructed which quantities to be used. ID also supervised the application of bio-slurry on these fields.

For less important operations, such as regular spraying on the leaves on the orchard, the beneficiaries were asked to keep a "logbook" of all operations (see illustration 1), indicating the date, the product used, and the quantity.

The beneficiaries were in first line for observing and evaluating the efficiency of the treatments and reporting any observed differences or interesting facts. Since the team of ID China could only visit the terrain every two to three weeks, the qualitative judgement/monitoring relied therefore essentially on the beneficiaries. We met the beneficiaries on nearly every field visit and listened to their remarks and observations. To complement the farmer's opinion with an objective method for judging the efficiency of the fertilisation plans, the team of ID China carried out quantitative statistical measurements group per group, as described in the next sections.

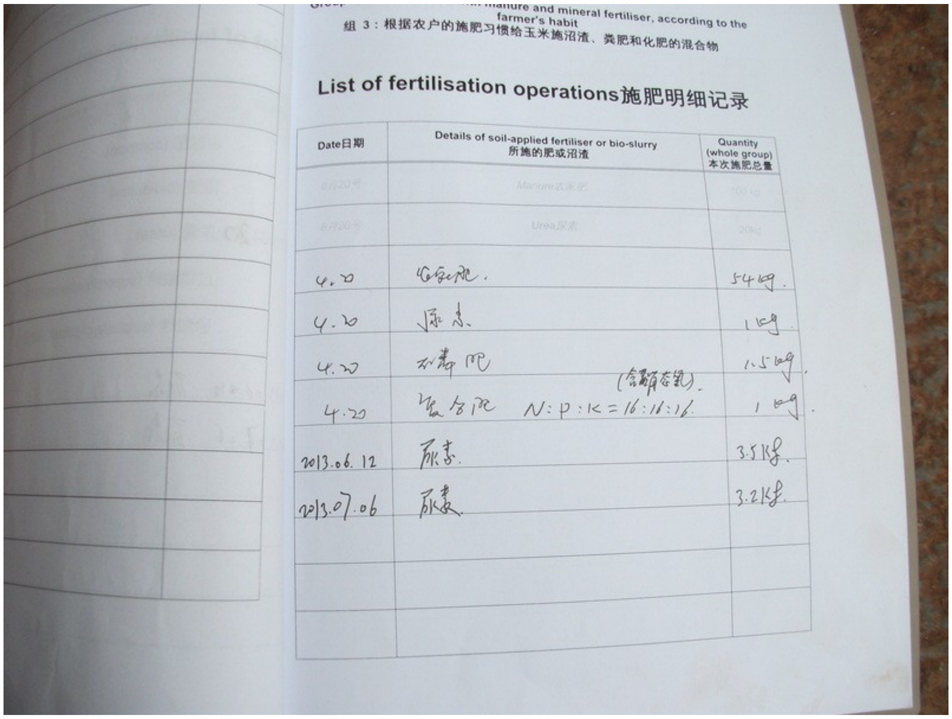


Illustration 1: "Logbook" used by the beneficiary

3.4 Guarantee for the harvest

As a side effect of the experiment, the health or yields of the crops could have been affected on the groups on which bio-slurry was used. ID China therefore proposed an insurance mechanism to compensate financially any potential losses attributed to the experiment. Surprisingly, all three beneficiaries were displaying very strong confidence in the experiment and initially brushed aside the proposal on the motive that the harvest was not at stake. However, to prevent any possible future misunderstanding, ID China insisted on passing an insurance scheme and a contract was signed. The deal proposed a compensation in cash equal to the loss of harvest, if any, at the current market price (yields were to be weighed at the end of the experiment, if necessary).

3.5 Delimiting the plots

The experiments were designed to closely follow real terrain conditions amongst the beneficiaries of ID China, therefore the chosen fields/orchards were small and irregularly shaped, representative of the fragmented and hilly agricultural landscape of northern Yunnan. One orchard was even split in two terraces on the slope. Larger fields could not have been found amongst the beneficiaries of ID China, which are, by reason of the NGO's mission, chosen amongst the less well-off farmers. Such conditions, however, worked against experimental accuracy, which would have required larger, regular, well demarcated plots.

The groups were initially marked with a string and a plastic-laminated sign on a post. However, the beneficiaries soon removed the marking on preventive grounds, fearing that it would provide an entertainment for local children. The signs that were nevertheless left in place did, indeed, eventually suffer this fate.

Illustration 2: Tobacco experimental field in XiaoLongDong (小龙洞) township

3.6 Quantitative monitoring

3.6.1 Corn

Germination rate

At planting time, 3 corn seeds were sown in every planting hole. The germination rate was monitored twice in the weeks after planting.

To determine the germination rate, a portion of a planting row was chosen randomly, and the number of emerged corn seedlings were counted on 50 consecutive planting holes. The germination rate is calculated by:

$$Emergence\, rate = \frac{number\ of\ emerged\ seedlings}{3*50}$$

Height

The height of 10 corn plants was measured. For selecting the plants to measure, a pseudo-random method was used to eliminate the observer's biases: the observer was walking along a planting row and selecting every fifth plant. The two first planting holes on the edge of the field were excluded from the measurements.

Size and number of the corn ear(s)

On each of the pseudo-randomly corn plants chosen as described above, the number of corn ears were written down, as well as the length of the biggest ear.

Final yield

The final yield was estimated by measuring partial yields on selected portions. Four portions of 4m were selected randomly on the field and all the corn ears were harvested and weighed.

3.6.2 Potato

Germination rate

The germination rate was measured in a similar way to the corn. At planting time, a quarter of a potato was sown in every planting hole (illustration 4 page 16).

To determine the germination rate, a portion of a planting row was chosen randomly, and the number of emerged potatoes counted on 50 consecutive planting holes.

Height and width

An attempt was made at measuring the height and width of potato plants. However, these are not effective indicator of growth, since the plant stems tends to fall back to the ground. The measurements were therefore discontinued.

Number of stems

The number of emerging stems, out of each planting hole, was counted. 10 plants were chosen according to the pseudo-randomized method described above, and for each the number of stems was counted.

Final yield

The final yield was estimated by measuring partial yields on selected portions. Four portions of 4m were selected randomly on the field; all the potatoes were dug up and weighed.

3.6.3 Tobacco

Crop height

The crop height was measured. 10 plants were chosen randomly in the field and measured.

3.6.4 Apple

Terminal tip growth

The length of the terminal shoot growth was monitored, since it is known to provide a indication of nitrogen supply. During each field visit, four tips were measured on each tagged tree.

Apple size

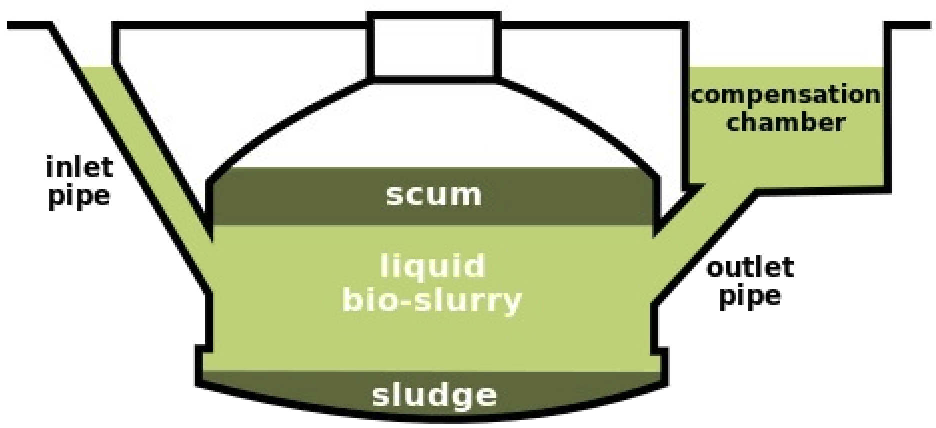
The size of the fruits was monitored. On each tree, 10 apples were chosen randomly and their diameter was measured.

4 RESULTS AND DISCUSSION

4.1 Bio-slurry characteristics

All the bio-slurry used for the field experiments was sourced from the beneficiaries' own biogas digester, which were 10m³ fixed-dome “Chinese model” digester built with the help of ID China between 2009 and 2012.

The content of these kind of digesters separates naturally by flotation and sedimentation. Hence, three types of biogas by-products can be distinguished[2]:



- The **scum** floats at the surface of the liquid, and is made of the bulk of fibres and plant residues, such as stalk and straw. The beneficiaries of ID China's biogas programs usually remove the scum once a year in January/March. The top lid is opened, the floating crust is broken and agitated with a wooden pole, and the floating residue is scooped out with a bucket. This fraction has a wet manure-like fibrous form, with more or less liquid depending on extraction and storage. Since biogas is called 沼气 in Chinese, literally “marsh gas”, this fraction is referred to as 沼渣, literally “marsh residue”.
- The **sludge** are the heavy particles such as sand which settle at the bottom of the tank. It does not need regular emptying. The beneficiaries rarely empty the digester completely.
- In between these two layers the content is mainly liquid. The height of the outlet tube leading to the water compensation chamber is built to match this liquid layer, so that the compensation chamber does usually not suck in the solid particles. The term “**bio-slurry**” usually applies to this fraction. It is a black liquid containing few or no solid particles. In Chinese the liquid fraction is generally referred to as 沼液, literally “marsh liquid”.

[2] Bioslurry = brown gold? A review of scientific literature on the co-product of biogas production. Lennart de Groot, Anne Bogdanski, FAO, 2013. p1.

For all the experiments described here, the liquid fraction was used (extracted from the water chamber), and was therefore generally free from solid particles. For use in the sprayer, the liquid was however filtered either through a piece of cloth or through the integrated sieve (illustration 11). No clogging of the spraying nozzle was reported.

Table 5 presents the typical chemical characteristic of bio-slurry as we assumed for this report. These figures are averages of 6 samples taken in April 2013 on three biogas digesters in Zhaotong prefecture. On each digester a sample of liquid bioslurry was taken from the water chamber, and a sample of semi-solid bio-slurry was taken from the floating scum through the main lid. Note that these are chemical analysis of another bio-slurry than the one effectively used for the experiments, so the figures should be taken as typical values only.

	pH	Humidity %	Organic Matter %	Total N %	Rapidly available N %	Total P_2O_5 %	Total K_20 %
Liquid fraction	7.6	99.01	0.49	0.12	0.10	0.02	0.04
Solid fraction	7.4	92.84	3.82	0.24	0.12	0.04	0.04

Table 5: Typical chemical analysis of bio-slurry

4.2 Intercropped corn/potato

4.2.1 Treatments

On Ben1's field the planting took place on the 2nd of April 2013. Corn and potato were planted on the same day. The beneficiary was helped by a dozen relatives and people from the village, but spent himself only little time on the field. The situation was confusing and difficult to manage, because many people were waiting to proceed to the planting and trying to help with the fertilisation, while our team of two had to organise and record the fertiliser quantities.

We noticed on that occasion the strength of the rural habits, based on a long acquired knowledge, as people were trying to discourage us to use the fertilisers in any different way to the usual practise. Although the fertilisation amounts and methods had been discussed and agreed with the beneficiary long in advance, and although the beneficiary had been enthusiastic about the project, unfortunately he was himself not present on the field to back the trial. Another factor for the reluctance of the farmers may have been that as long as fertiliser methods are stated on paper they appear most abstract, but once they are translated into actual handfuls their difference jumps to the eye. Our team had to provide arguments to justify the experiment, as a mean to explore potential new techniques.

The process of planting was managed by the farmers. Our team was responsible for calculating, weighing and distributing the fertilisers on plots 1 and 2. On plot 3, the farmers used their usual quantities of the usual fertilisers, which were estimated and written down.

Illustration 3: Tray of seed potatoes and dry manure

The process of planting corn and potato takes place in several steps. First of all, the future planting rows are sketched on the soil. The planting holes are then dug with the help of a hoe in two parallel rows 30 cm apart. Each of these double-rows of corn is alternated with a double-row of potato.

Illustration 4: Planting hole, note the manure and the fertiliser beside the seed potato

In a second step, each hole receives a handful of dry cow manure. In the case of potato, the seed potatoes (usually sliced in four) are carried in the same tray as the dry manure and thrown in the hole together in a single move (illustration 3).

A handful of fertiliser is then thrown in the planting hole, on the side so to not touch the seed potato, or to leave place for the corn seeds. The farmers take great care in avoiding direct contact between the fertiliser and the seed (illustration 4).

The fertiliser is usually a pre-mixed association of several fertilisers available on the market. To gain time on the field and not have to dispense several products, the farmers mix the fertilisers together at home and carry the blend to the field in bags. The blend is then transferred in buckets to move around on the field. The size of the handful is known by experience by every planter and seemed rather homogeneous amongst the people we observed.

For the corn, three seeds are then placed in every hole, spaced from each other and away from the fertiliser. Finally, all the holes are filled with soil with the hoe. On most fields, the rows are then covered in plastic foil, but in this case the farmers decided not to do so.

The description above applies to group 3, on which the farmers were asked to proceed as usual.

4.2.1.1 Groups 1 and 2 – specific use of bio-slurry

On the groups 1 and 2, liquid bio-slurry was used in the planting process.

The bio-slurry was poured in the planting hole and was added first. In other words, were sequentially added:

- potato: bio-slurry, manure+potato, mineral fertilisers
- corn: bio-slurry, manure, mineral fertilisers, seeds

After the bio-slurry was poured in the hole, it was left so percolate down in the soil. Since the soil on this field was very draining, most liquid was absorbed within minutes.

The fertilisers were then weighed, row by row, and distributed in the planting holes, away from the seeds. Three fertilisers were applied: urea, superphosphate and sulphate of potash. These three fertilisers were not pre-mixed, instead they were distributed individually. However, two different placement of the fertilisers were tried:

- in group 1, half the group (group 1A) received all fertilisers in the planting hole
- in the other half of group 1 (group 1B) and in group 2, the urea was placed in the planting hole, while the superphosphate and the sulphate of potash were top-dressed and raked in the first 5 cm of soil.

Despite the good drainage of the soil, some planting holes still contained liquid by the time the seeds and the fertilisers were added (illustration3). In these less draining planting holes (about a quarter of all holes), it was not possible to place the fertilisers or the seed away from the pool of bio-slurry, and some mixing did occur.

Illustration 5: Liquid bio-slurry still infiltrating in the planting holes, while the seed potatoes have already been placed

4.2.1.2 Interactions between bio-slurry and the mineral fertilisers

Superphosphate

An unexpected reaction happened when superphosphate fertiliser was brought in contact with bio-slurry. The mixture immediately started fizzing and foaming intensely. The fizzing led to increased mixing of the fertiliser in the slurry. The explanation for the sudden release of gas is not yet clear.

It is clear that this until this interaction is proven innocuous, bio-slurry should not be used in conjunction with superphosphate.

Urea

Regarding potential interactions between urea and bio-slurry, it should be noted that when ammonium is released from urea through enzymatic breakdown in the soil, the addition of an alkaline solution such as bio-slurry could enhance ammonia volatilisation from the soil according to the equilibrium reaction:

$$NH_4^+ + OH^- \leftrightharpoons NH_3 + H_20$$

Therefore, it is probably not advisable to use liquid bio-slurry on the soil together with urea (as was done in this field trial), or to top-dress bio-slurry in the weeks following urea application.

Illustration 6: Transport of bio-slurry on horse back

4.2.1.3 Transport of the bio-slurry

The bio-slurry was brought to the field in 30 litres plastic cans which were harnessed to the horse. The field was situated a 10 minute walk away on a steep uphill, and was only accessible by foot, so the 5 trips with the horse to bring bio-slurry were particularly tiresome. Out of all the required materials necessary for planting (seeds, fertilisers, compost), bio-slurry required by far the most effort for transport.

The beneficiaries have estimated that transport is the principal drawback of using bio-slurry rather than other fertilisers.

4.2.1.4 Summary of treatments

The different treatments are summarised in the following tables.

The fertiliser types, quantities and date of application are presented in table 6 (potato) and 7 (corn), while the total equivalent quantities of nutrients available to the crop, per mu (1/16 ha), are presented in illustration 7 (potato) and 8 (corn). The “Defra” bar shows the fertiliser recommendation as in DEFRA fertilisation manual (2010). The “Fertilisation station” bar shows the recommendation of the governmental fertilisation station of Zhaotong prefecture.

Although corn and potato were intercropped, all quantities are understood **as if the crop was planted alone**, i.e. only the actual surface of the crop is considered.

Potato					
	When	**Treatment**	**Location**	**Quantity kg/mu**	**Quantity kg/ha**
All groups	Planting 1st of May	Cow manure	Planting hole	700	11t
Group 1	Planting 1st of May	Bio-slurry	Planting hole	1000	15t
		Urea (46-0-0)		24	360
		Superphosphate (0-16-0)	Planting hole (1A) Top-dressed (1B)	32	490
		Sulphate of potash (0-0-50)		13	200
Group 2	Planting 1st of May	Bio-slurry	Planting hole	1000	15t
		Urea		24	360
		Superphosphate	Top-dressed	72	1100
		Sulphate of potash		20	300
Group 3	Planting 1st of May	Urea	Planting hole	15	230
		Ca-Mg phosphate fertiliser (0-12-0)		38	580
		Composed fertiliser (16-16-16)		15	230
		Diammonium phosphate (18-46-0)		8	120

Table 6: Table of treatments for potato

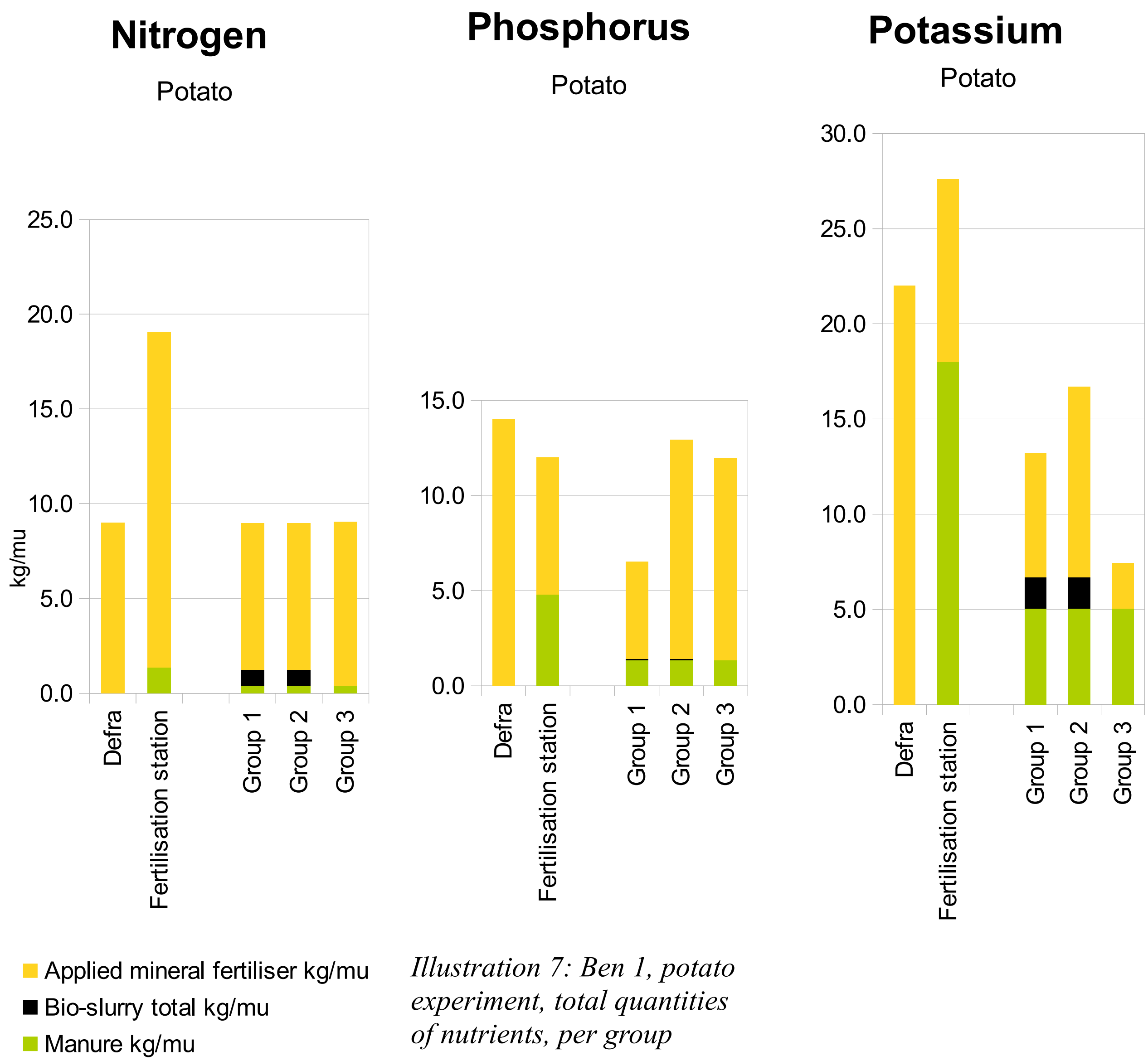


Illustration 7: Ben 1, potato experiment, total quantities of nutrients, per group

Corn					
	When	**Treatment**	**Location**	**Quantity kg/mu**	**Quantity kg/ha**
All groups	Planting 1st of May	Cow manure	Planting hole	400	6t
Group 1	Planting 1st of May	Bio-slurry	Planting hole	1000	15t
		Urea (46-0-0)		65	970
		Superphosphate (0-16-0)	Planting hole (1A) Top-dressed (1B)	55	830
		Sulphate of potash (0-0-50)		23	350
Group 2	Planting 1st of May	Bio-slurry	Planting hole	1000	15t
		Urea		4	60
		Superphosphate	Top-dressed	24	360
		Sulphate of potash		6	90
Group 3	Planting 1st of May	Urea	Planting hole	8	115
		Ca-Mg phosphate fertiliser (0-12-0)		38	580
		Composed fertiliser (16-16-16)		8	115
		Diammonium phosphate (18-46-0)		8	115
All groups	22th of May	Urea	Top-dressed	35	530
	1st of July	Urea	Top-dressed	94	1400

Table 7: Table of treatments for corn

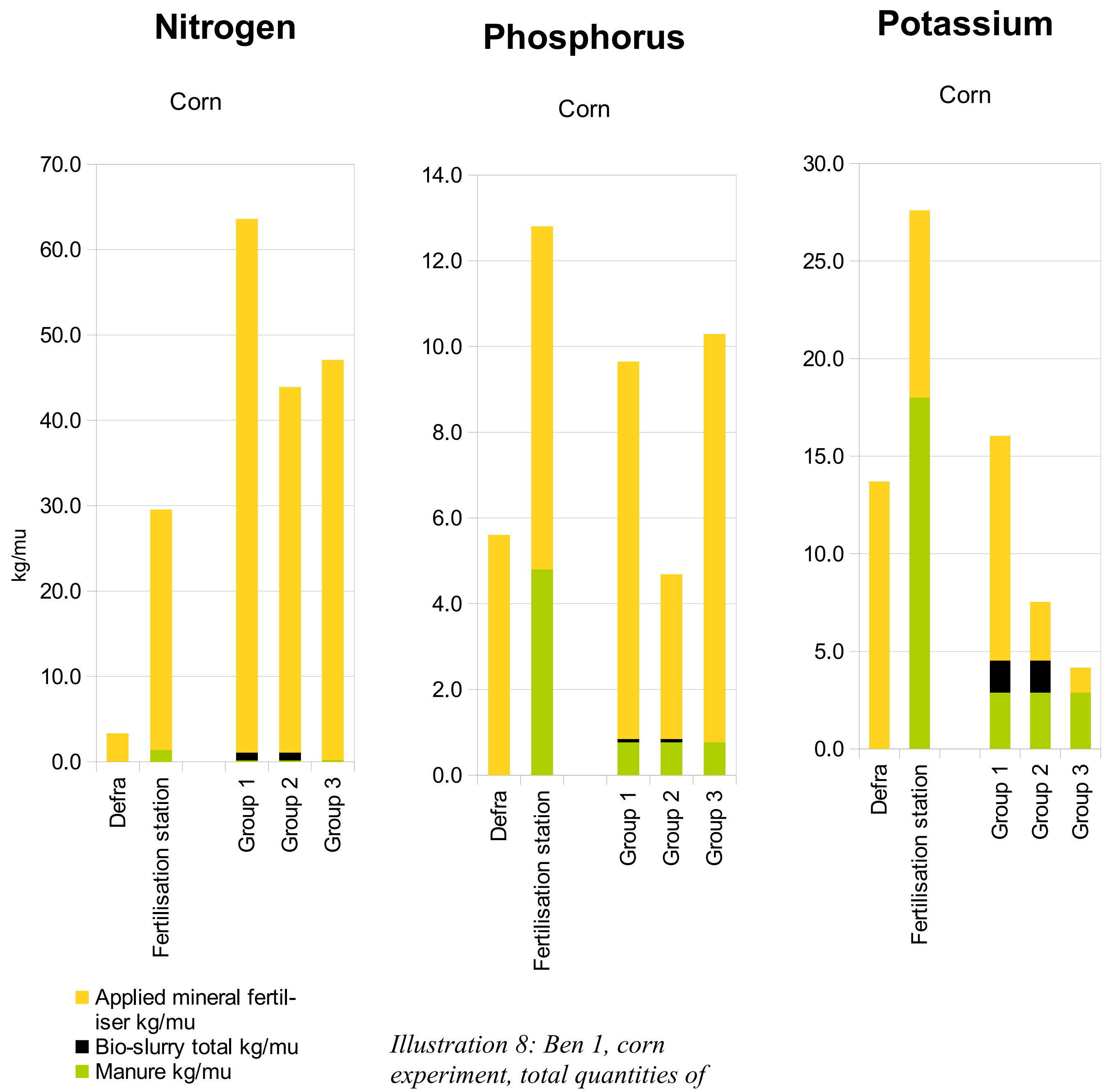


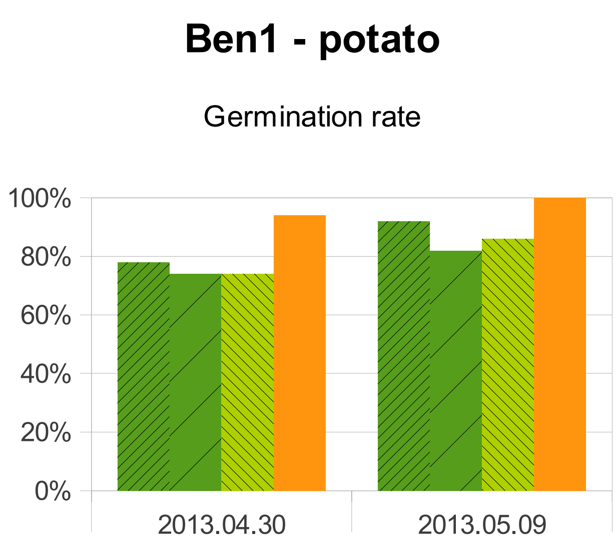
Illustration 8: Ben 1, corn experiment, total quantities of nutrients, per group

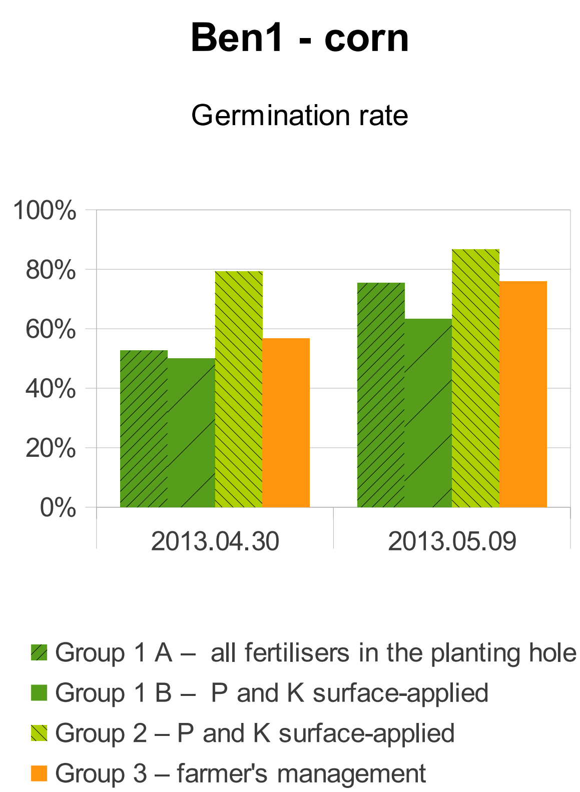
4.2.2 Results

In illustration 9 the experimental plot can be seen at two different times in the growing season. Detailed measurements can be found in the following sections.

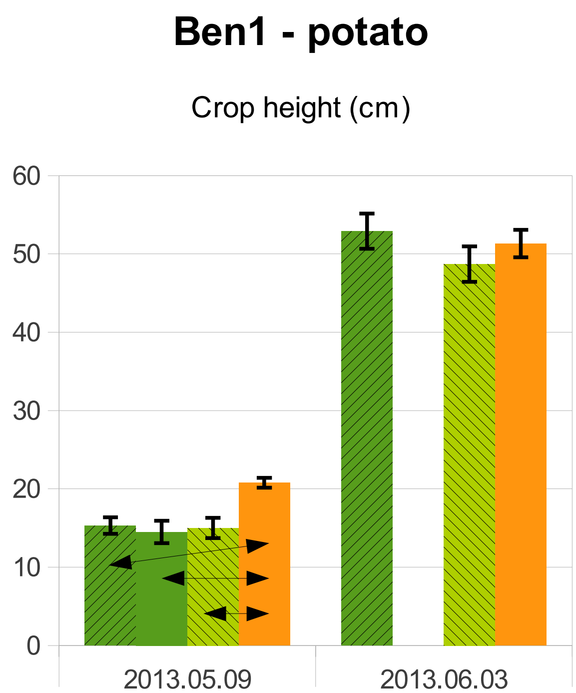
Illustration 9: Experimental plot photographs on the 9th of May and 16th of July

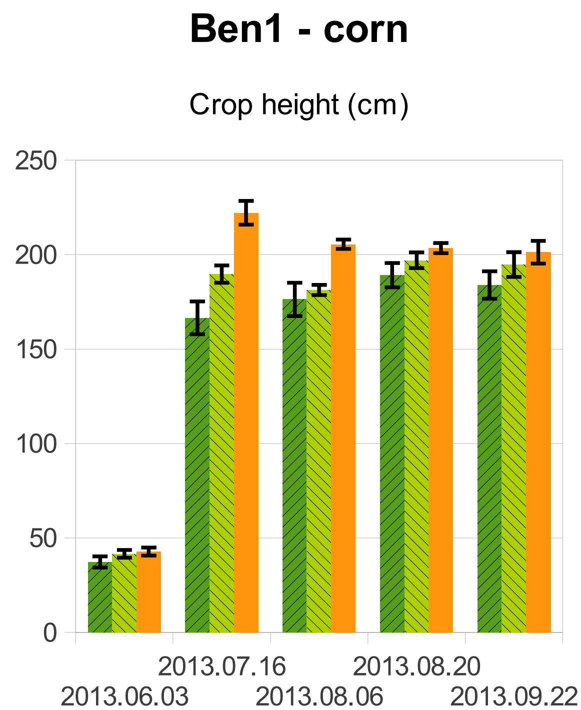
4.2.2.1 Germination rate



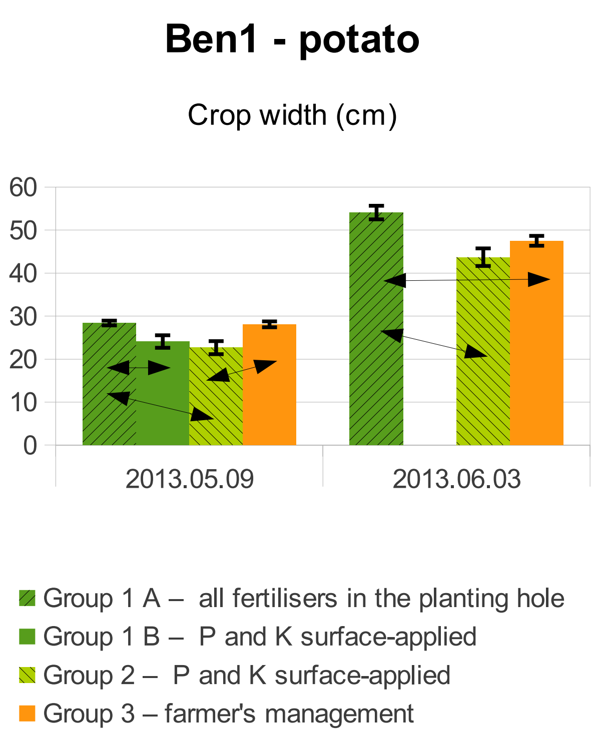


4.2.2.2 Crop size





Bars show standard errors of the mean.

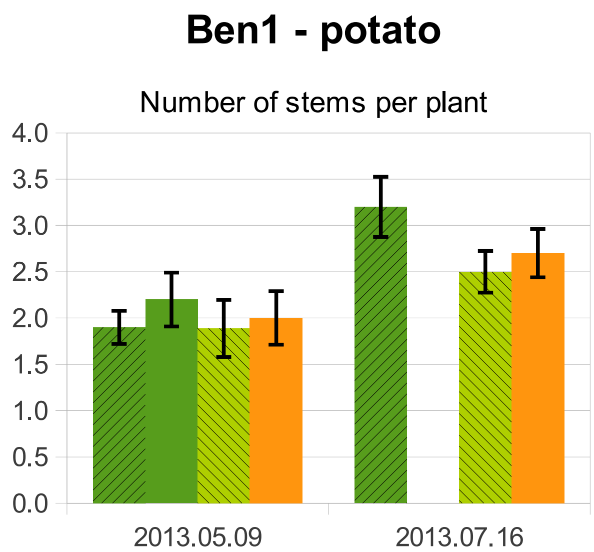


ANOVAs were performed on the data at a level of significance of 5%.

On potato, where significant differences were found they have been indicated on the bar plots using arrow lines.

On corn, for the ANOVA data from the four last field visits have been aggregated since the crop had roughly reached its final height already. Mean aggregated heights in the three groups are 179, 191 and 208 cm for groups 1, 2 and 3 respectively. All differences between groups are significant. Differences on the first field visit (3rd of June) however are not significant. It shall be noted that the bio-slurry groups had a slower growth, before partially catching up, although not reaching the same final height as the non bio-slurry group.

4.2.2.3 Number of potato stems



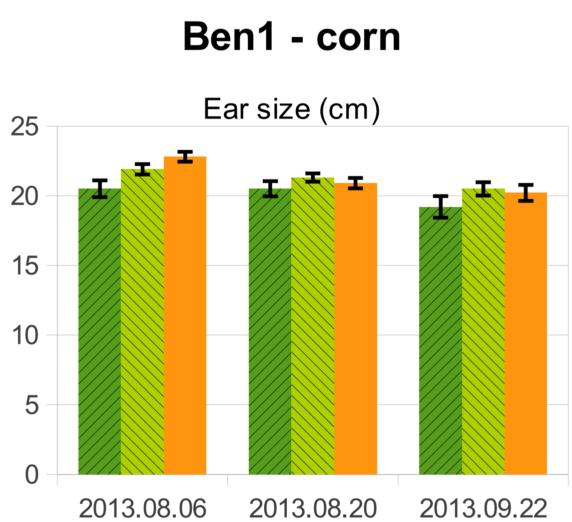
ANOVAs were performed on the data at a level of significance of 5%.

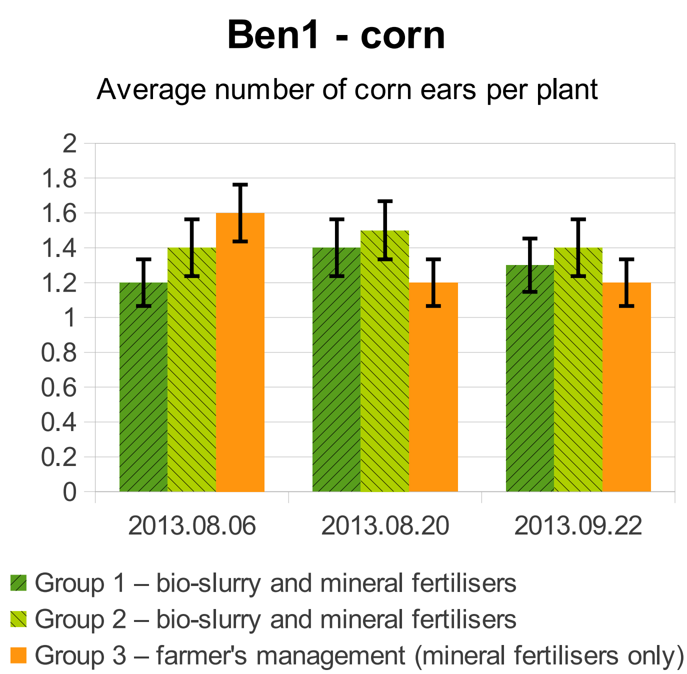
On potato, the difference in number of stems per plant was not found to be significant.

4.2.2.4 Corn ears

On corn, the ear size data has been aggregated for the three field visits, since the corn apparently reached its final size already. Mean aggregated ear sizes in the three groups are 20.1, 21.2 and 21.3 cm for groups 1, 2 and 3 respectively. Differences between group 1 and the two other groups were significant.

Data for the number of ears was also aggregated, differences were not significant.

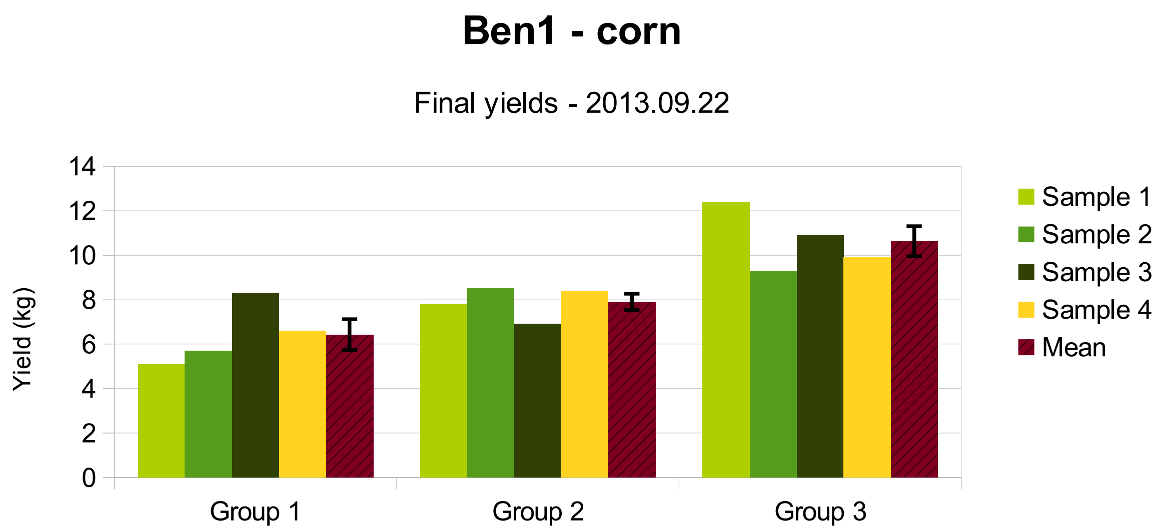




4.2.2.5 Final yields

Four samples were taken on each group. Each sample was weighed from a 4m long portion of a planting row. The results are shown in illustration 10.

ANOVAs were performed on the data at a level of significance of 5%. On corn, significant differences appear between group 3 and the two other groups. On potato, the differences are minimal and were not significant.



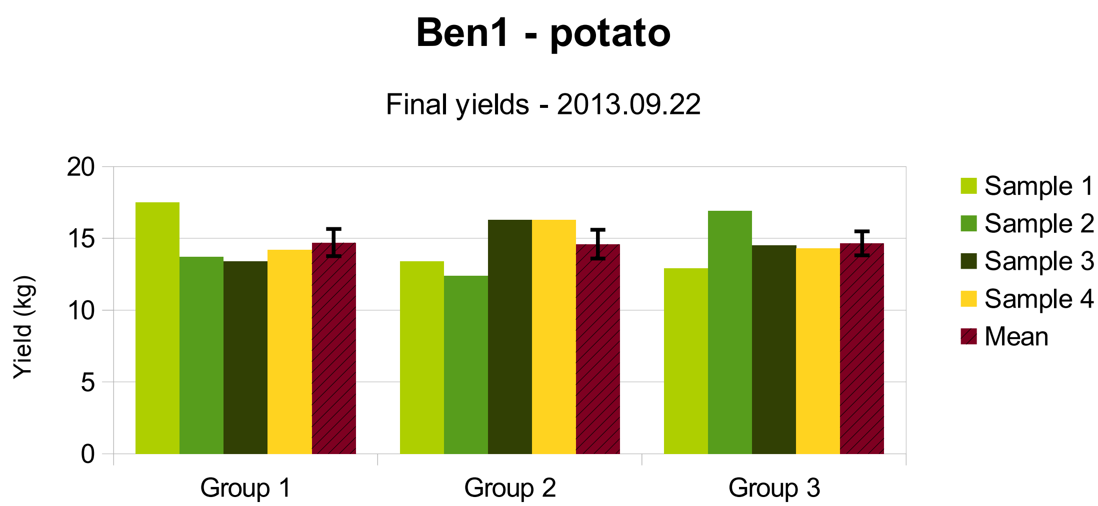


Illustration 10: Corn and potato yields. Bars show standard error of the mean.

4.2.3 Conclusions

4.2.3.1 Potato

The emergence rate was found to be lower by 10 to 20% in the groups that received bio-slurry. According to the farmer, an excessive amount of fertiliser is to blame for the poor emergence rate. However, there is little evidence to support this thesis, since group 2 received a very small amount of fertiliser. Indeed, groups 1A, 1B and 2 received very different fertiliser quantities and application methods. Therefore there is better evidence to suggest that bio-slurry, as a common treatment to these three groups, had a negative impact on potato germination.

Since the phosphate and potash have been top-dressed in groups 1B and 2, the low emergence rate cannot be blamed on the contact of the seed potato with these fertilisers. However, it is still possible that the reason for low germination is that the presence of liquid bio-slurry in the planting hole increased the contact between the seed potato and the urea.

The growth of potato in the bio-slurry groups was significantly slower, as attested by the pictures and the measured data. However, the crop caught up to reach similar height and width within two months.

The final yield in the three groups was almost identical, although less plants had germinated per unit of surface in groups 1 and 2. Therefore, the yields per plant must have been increased in the bio-slurry groups.

Altogether, it can be concluded that the fertilisation with bio-slurry in the planting hole, as described above, had a negative impact on germination and early growth. On later growth and yields, the effect of bio-slurry are not obvious in this study, since other parameters predominated (in particular, different amounts of mineral fertilisers).

Concerning the total quantities of fertilisers and their effect on the yields, it shall be noted that similar yields were achieved on all three groups for roughly equal inputs of nitrogen. Globally, only an estimated 11 % of the mineral fertiliser was replaced by bio-slurry on groups 1 and 2, on a nitrogen base.

4.2.3.2 Corn

Whether germination rates of corn have been affected by bio-slurry does not appear clearly. Indeed, only group 2 presents a distinctively higher germination rate. In general, corn germination is know to be affected by the proximity of fertilisers, which is why farmers take great care in avoiding all contact in the planting hole. The fact that group 2 received the lowest amount of fertiliser could confirm this observation. Our observations might therefore rather point at the negative impact of fertilisers on the germination rather than at the effect of bio-slurry. However, it was noticed on the terrain that on the groups treated with bio-slurry the germination, although not reduced, seemed slightly delayed and that the seedlings looked less vigorous.

The growth and final height of the crop was significantly slower on the bio-slurry groups, and the effect was strongest on group 1. Ear sizes were significantly smaller on group 1. Possibly, the negative impacts of bio-slurry and of excessive mineral fertilisation could have summed up on this group.

Final yields were significantly higher on the non bio-slurry group (-40% and -26% for groups 1 and 2, respectively). This appears to be due to a higher yield per plant, rather than to a higher plant density, as possibly confirmed by the slightly higher ear size on group 3.

Altogether, it can be concluded that the fertilisation with bio-slurry in the planting hole, as described above, had a negative impact on early growth, but not on germination. Rather, the germination appears to be negatively affected by the amount of urea placed in the planting hole. On later growth and yields, the effect of bio-slurry are not obvious in this study, since other parameters predominated (in particular, different amounts of mineral fertilisers).

Concerning the total quantities of fertilisers and their effect on the yields, it shall be noted that the yield of group 1 was lower although more nitrogen was provided to this group. Globally, only an estimated 1.3 % of the mineral fertiliser was replaced by bio-slurry on groups 1 and 2, on a nitrogen base.

4.2.4 Placement of the fertilisers

As can be seen above, the exact placement of the fertiliser is likely to play an important role on the crop growth, and in particular on the germination.

On groups 1B and 2, phosphate and potash were distributed on the whole surface of the planting row rather than in the planting holes (as usually done). This procedure was adopted since plants are less reactive to phosphorus and potassium availability than they are to nitrogen supply. Phosphorus is so immobile and locked in most soils that phosphorus supplied in the year is generally not made available to the plant, but rather joins the soil stock. Hence, placing these fertilisers very close to the root is not necessary. By broadcasting them on the whole field surface, their supply can be better regulated, leaching can be reduced, and potential harm to the seed can be avoided. (However, as the germination data above has shown, superphosphate and sulphate of potash did not seem to have negative impacts on germination when placed in the planting hole).

While proceeding with the surface application of these fertilisers, we were discouraged by an elderly man to do so, arguing that it would give a selective advantage to the weeds. This sensible argument is probably determinant in the farmer's choice to apply the fertiliser directly to the planting hole. Since the agriculture in the region is not mechanised, fertilisers are always distributed by hand, and farmers rarely broadcast, preferring to place the fertiliser as close to the crop roots as possible to maximise availability and reduce uptake by weeds. The weed growth was unfortunately difficult to efficiently monitor on the different parts of the field, so it is not possible to conclude whether surface application favoured weed growth.

Finally, the placing of the bio-slurry seems equally important. The negative effects of supplying bio-slurry in the planting hole have been shown above. Another strategy was used on the tobacco, as reported in the next sections.

4.3 Tobacco

4.3.1 Treatments

Transplanting took place on the 1st of May. The tobacco seedlings were sourced from the beneficiary's own nursery located on the field itself. The transplanting takes place in several steps as described below. The soil is first mounded in windrows about a meter apart. A series of holes are dug with a hoe along the mounds at an approximate distance of 50cm. Each planting hole receives a handful of dried cow manure, a handful of compound fertiliser and a handful of humid acid / micro-nutrients complex. The size of the handfuls are determined by the farmer by experience. The staff from ID China weighed the bucket before and after and measured the size of the plot, so the amounts per unit of surface could be calculated.

The fertilisers type, quantity and date of application are presented in table 8, while the total equivalent quantities of nutrients available to the crop, per mu (1/15 ha), are presented in illustration 15. The horizontal lines in the bar graphs shows the amounts recommended by the fertilisation station of Zhaotong.

Illustration 11: Distribution of the fertilisers in the planting holes

Illustration 12: Tobacco seedlings ready to be transplanted

The tobacco seedlings were then transplanted in the planting holes and watered (illustration 13). Finally, a layer of black plastic was stretched on the mount , the plastic was dug in place on the side, hole were punctured for the seedlings and more soil was shovelled around the seedling to maintain the plastic in place (illustration 14).

The beneficiary insisted for not using bio-slurry during transplanting, since the high nutrient content of the bio-slurry could harm the seedlings. Hence, the application of bio-slurry was delayed until the plants were better established in the beginning of May. Liquid bio-slurry from the beneficiary's own biogas digester was extracted from the water chamber and transported to the field in a cart-mounted metal cistern pulled by a tractor. The bio-slurry was then poured individually to every plant.

Illustration 13: Watering of the transplanted seedlings

Illustration 14: Completed transplanting

Furthermore, bio-slurry was used once by the beneficiary in foliar spray in the beginning of July. This application was mainly planned for our study on the efficiency of bio-slurry on pests and diseases (see the document “Using bio-slurry for pest control”), but also contributed potentially to the crop fertility through foliar absorption.

	What	Quantity kg/mu	When
Groups 1 & 2	Cow manure	600	1st of May
	13-11-24	85	1st of May
	Organic matter & micro-nutrients	50	1st of May
Extra group 1 only	Bio-slurry (soil application, poured at the foot of each plant)	750	10th of May
	Bio-slurry (foliar spray, 1 time, diluted 1:1 with water)	50	29th of June

Table 8: Treatments for tobacco

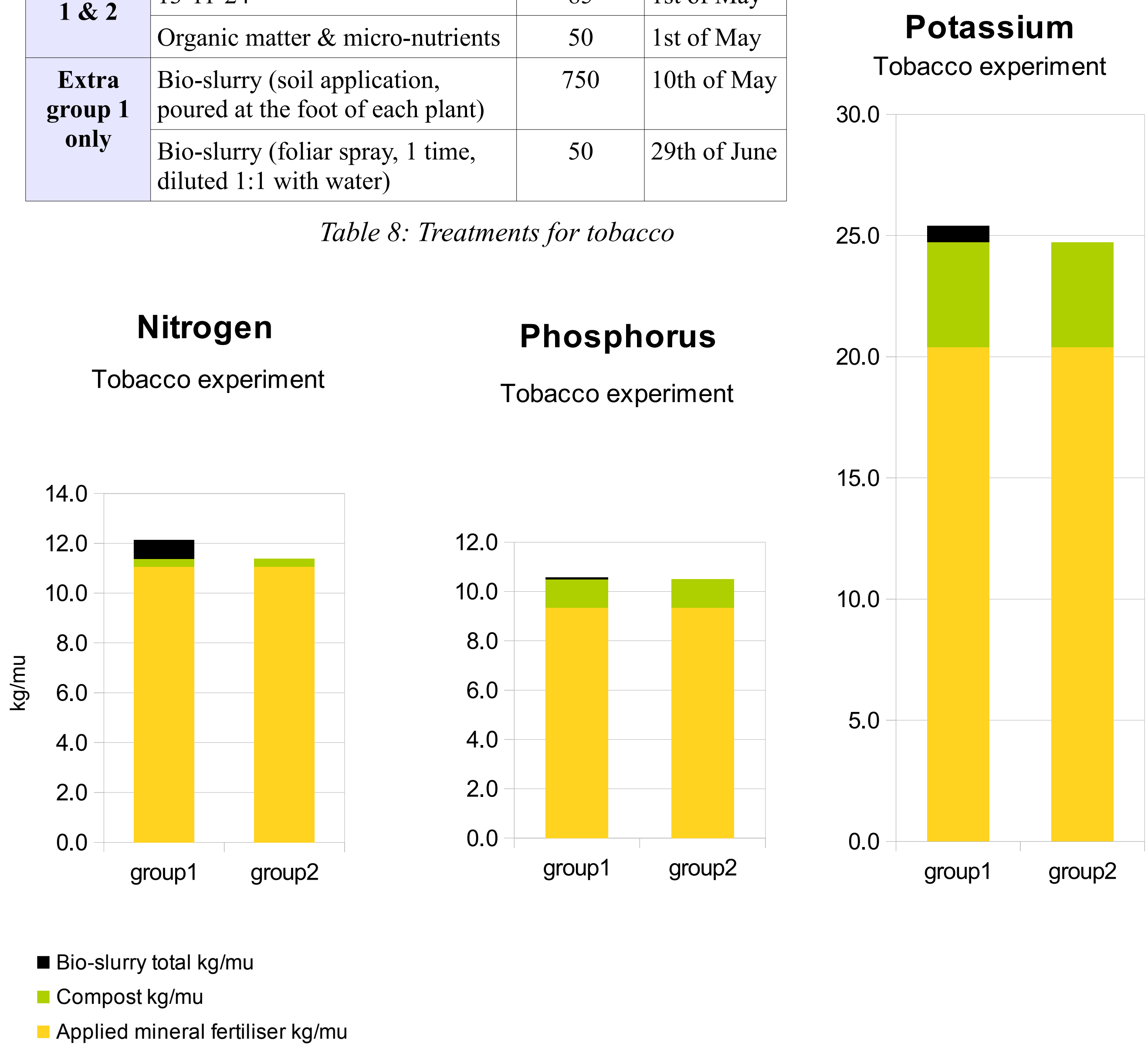


Illustration 15: Tobacco experiment, total quantities of nutrients, per group

4.3.2 Results

Although bio-slurry was only applied twice (once on the soil, once foliar), and although the theoretical amount of nutrients brought by these applications were marginal (see bar graphs in illustration 15), differences were noticed between the two groups on the leaf colour, ripeness, ability to cure and final quality after curing.

The colour of the leaves was distinctly darker green on group 1 (bio-slurry) compared to group 2. The difference in colour could easily be observed with the naked eye on the field. In general, however, the supply of nitrogen to tobacco should be restrained in late season to allow for proper curing. For this reason, the farmer decided to stop the spraying of bio-slurry after the first round. While the leaves from group 2 lost their green and turned progressively towards yellow colour, the colouring of leaves from group 1 was indeed delayed. After flue curing, these leaves achieved a lesser grade at selling point.

The difference in quality after flue curing was confirmed by a random sampling in both groups. Tobacco in the curing barn is held on sticks, each weighing approximately 1.6 kg. Five of these sticks, from the second priming ("seco" leaves), were taken randomly in each group. The beneficiary then pre-sorted and weighed the leaves in 3 quality grades, as is usually done by the farmers before taking their harvest to the tobacco manufacture. The repartition of the sample in categories is shown in illustration 16, while the market prices for the different categories can be found in table 9.

Category 3	4.50 ¥/kg
Category 2	7.50 ¥/kg
Category 1	11.50 ¥/kg

Table 9: Market prices of cured tobacco, Zhaotong 2013

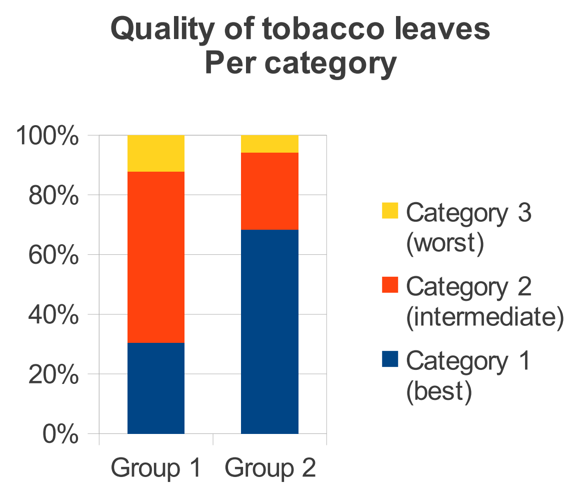


Illustration 16: Repartition of cured tobacco leaves by quality category

10 cured leaves from this priming were also chosen at random in each group and measured (length and width). No significant differences were found at a significance level of 5%. However, we could not ensure that all leaves were sourced from the exact same height on the plant, therefore the inner-group variation might have been exaggerated.

Furthermore, the height of the crop was measured twice, in early and late June. 10 plants were measured at random in each group. No significant difference was found at a significance level of 5%. The height in the field did not appear visually different either.

4.3.3 Conclusions

Although the quality of the leaves was obviously affected by the treatment, the yield of the two groups was not significantly different, since differences could be observed neither in crop height nor in leaf size.

The drawback of reduced leaf quality could potentially be an obstacle to the use of bio-slurry on tobacco, both for fertilisation and for pest control. However, if the problem is rather linked to the total quantity of nutrients provided, rather than to the specific effects of bio-slurry, then a compensating reduction in the quantity of soil-applied mineral fertilisers should correct the balance. Additional field trial could be done to confirm this possibility.

Because of the rapid and efficient absorption through the leaves, it is possible that the bio-slurry used in foliar spray contributed to the total leaf fertility disproportionately compared to the bio-slurry used on the soil, although the latter quantity was 15 times higher. The experiment cannot provide any indications to this effect, however.

From the farmer's point of view, the efficiency of the bio-slurry on both the fertility and the control of the diseases was tangible. The farmer has announced his intention to further experiment with bio-slurry in the following year, but with a reduction in mineral fertilisers.

Illustration 17: Tobacco in group 1, 18th of August

4.4 Apple tree

4.4.1 Treatments

For the apple orchards, a full fertilisation plan was proposed for every group and agreed with the beneficiaries. Bags of fertilisers were provided by ID. An appointment was made with the beneficiaries to proceed to the fertilisation. However, when our team came to the terrain on the said day, we learned that the fertilisers had already been applied to the orchard despite our instructions. The amounts differed from the agreed fertilisation plan and had not been written down by the beneficiaries, and it was only possible to reconstitute the records with limited confidence. Since the plan had already been modified, subsequent fertilisations were left to the beneficiaries' choice. Furthermore, one beneficiary did not fertilise with bio-slurry at all because of the difficulties of transport to the field.

Many different types of fertilisers were used by the beneficiaries, and the complete list is not included here. However, figure 18 shows, group per group for the two beneficiaries, the total equivalent quantities of the three principal nutrients nitrogen, phosphorus and potassium. The bar on the left shows the amount which is recommended by the fertilisation station of Zhaotong.

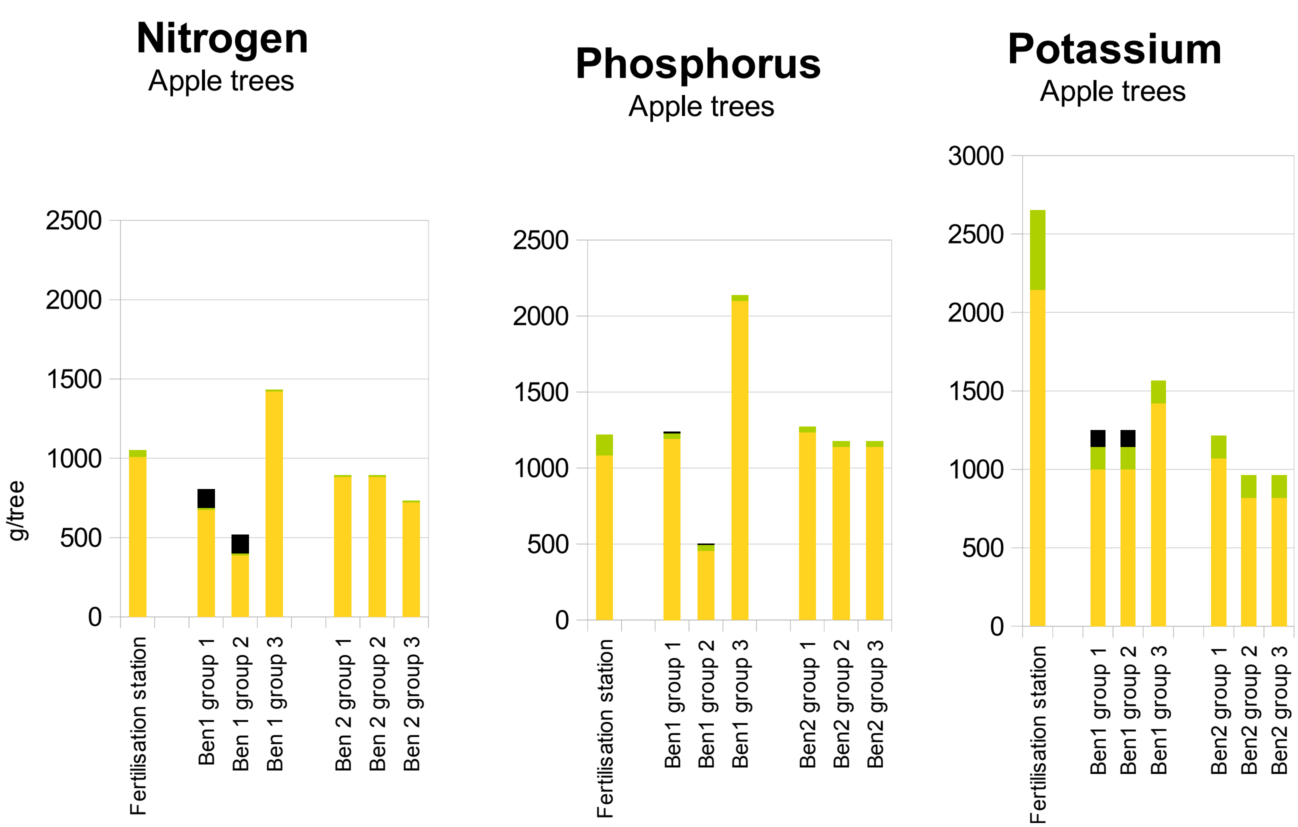


Illustration 18: Apple experiment, total quantities of nutrients, per group

Bio-slurry was applied on the soil by Ben1 twice, on the following dates: 16th of March and 16th of June. Each time the beneficiary applied 60 l/tree, which is roughly 2000 l/亩, or 32 t/ha.

Furthermore, bio-slurry was applied in foliar spray:

- Ben1 sprayed 4 times on the following dates (1.6 l/tree, or 60 l/亩 or 1000 l/ha, each time):
  2 April - 19 April -16 June -3 July
- Ben2 sprayed 5 times on the following dates (1.1 l/tree, or 100 l/亩 or 1600 l/ha each time):
  20 March - 7 April - 25 April -12 May - 27 June

For the foliar spray, the bio-slurry was diluted with water in a proportion of 1:1 to 2:1. The treatment was interrupted early in the season to avoid contaminating the fruit with potentially harmful pathogens (safe retrieval time). Furthermore, according to Spectrum Analytic (1991), nitrogen should be "allowed to decrease during the season, which will enhance the colour and flavour of the fruits. General soil nitrogen applications after July are not advisable. This may result in poor fruit over colour and late growth that can increase the hazards of winter injury to wood and buds. To improve fruit quality and colour (red varieties), nitrogen levels in trees should be low but not deficient as harvest nears. The nitrogen supply to apple trees should be kept low when nearing harvest to promote fruit maturity, colour and taste.". Foliar sprays high in nitrogen should therefore be avoided as harvest nears.

Illustration 19: Discussions in Ben1's orchard

4.4.2 Results - Ben1

Despite the lack of confidence on the quantities of fertilisers that had been applied to the soil, and although the initial fertilisation plan was not respected, it was decided to monitor the fertility of the apple trees nevertheless.

The colour of the leaves, a good indicator of fertility, was observed at each field visit every three weeks. In the opinion of the beneficiaries and ID staff, the leaves were looking slightly lusher on the bio-slurry groups, which might indicate a higher nitrogen supply. No sign of nutrient deficiencies was observed.

Terminal shoot length was also monitored on each tree. For each individual field visit, a nested ANOVA was performed on the collected data (3 groups, 4 subgroups, 4 measurements in each subgroup). No significant difference was noted between the three groups at a significance level of 5%, except for the last field visit on the 16th of July (see table 10 page 38). In general, most of the variance component was within sub-groups rather than between sub-groups. This indicates that for further experiments, it would be preferable to increase the number of shoots measured, rather than increasing the number of measured trees in each group. However, in general the terminal shoot growth proved to be a poor indicator for the statistical measurement of fertility, because of its high variability within a single tree. We only selected main tips on the branches, and eliminated side tips as well as tips on branches that had been pruned, but high differences remained. As illustration 20 shows, the average terminal shoot growth has been consistently higher on groups 1 and 2 during all field visits, but this difference was not significant. With better indicators, such as leaf nutrient analysis, differences in fertility could have been highlighted with better significance.

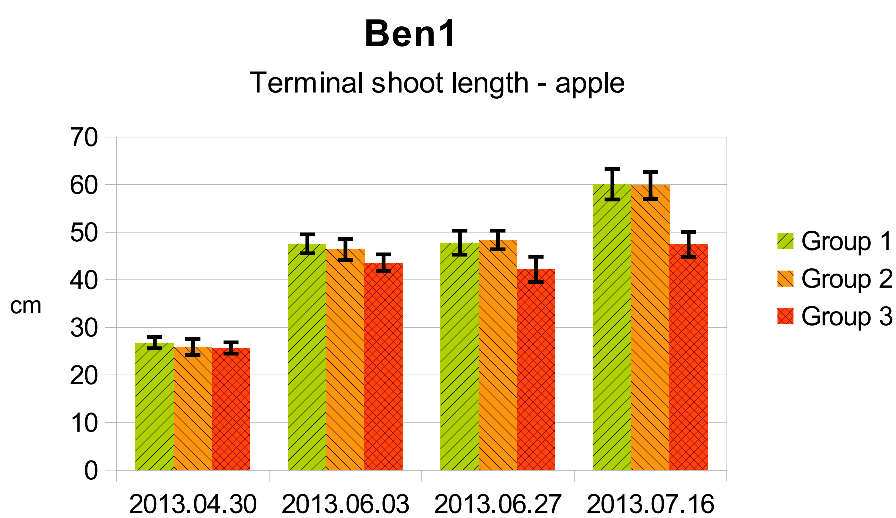


Illustration 20: Terminal shoot length, aggregated data from the four target trees, Ben1. Lines show standard error.

	sum of squares	d.f.	mean square	Fs	P	variance component (percentage)
among groups	1667.1667	2	833.5833	4.8588	0.0371	23.44
subgroups within groups	1544.0625	9	171.5625	1.3951	0.2267	6.88
within subgroups	4427.2500	36	122.9792			69.68
total	7638.4792	47				100.00

Table 10: Nested ANOVA on terminal shoot growth, Ben1, 16th of July 2013

The length of the yearly tip growth is a useful indicator for the supply of nitrogen to the tree. According to Spectrum Analytic (1991), the average terminal growth for a bearing tree should be comprised between 10cm and 30cm for a normal nitrogen supply; less than 10cm for low nitrogen supply; and between 30cm and 50cm for high nitrogen supply. The absolute results mentioned above therefore probably show that the nitrogen fertilisation on the apple trees was very high.

Finally, the size of the fruit was monitored. During the last three field visits (27 June, 16 July, 6 August), 10 apples were randomly chosen on each tagged tree (trees marked 1-2-3-4), and their diameter was measured. For each individual field visit, a nested ANOVA was performed on the collected data (3 groups, 4 subgroups, 10 measurements in each subgroup). No significant difference was noted between the three groups at a significance level of 5%. At least 90% of the variance component was within sub-groups. It is not possible to conclude whether the treatments had any influence on the apple size. However, considering the important variance in apple size on a given tree, we should not recommend this measurement criteria for upcoming experiments, at least with this sample size.

The yield of the trees was not monitored, since doing so would pose many methodological problems. In particular, the trees were of different size, and the apples are harvested progressively as they ripen.

4.4.3 Results - Ben2

Ben2's orchard was subjected to the same monitoring as Ben1.

No difference was observed in leaf colour or signs of nutrient deficiencies on the leaves between the three treatment groups.

No significant difference was noted in terminal shoot growth between the three groups at a significance level of 5%. In this orchard however, the variance was distributed rather equally between its component within sub-groups and between sub-groups. In other words, the variance was proportionally more due to the trees than in the other orchard, and less to the individual branch tips. This shall come as no surprise, as Ben2's trees were less homogeneous in age and size. Unfortunately, we had selected a few younger trees in group 1, which had a more vigorous growth. The terminal shoot growth is shown in illustration 21. It shall be noted that the average terminal shoot growth was recorded as *decreasing* between the field visits of 3rd and 27th of June. Unless it is due to pruning by the beneficiary, this could show the scale of the imprecision of the measurements.

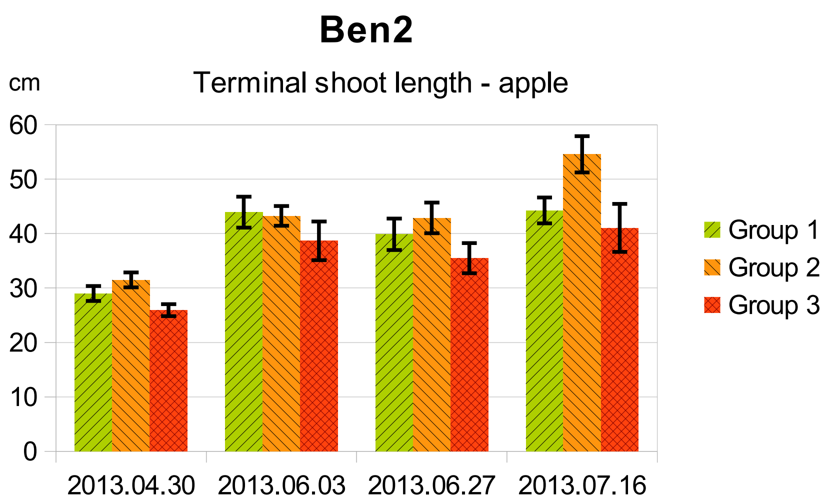


Illustration 21: Terminal shoot length, aggregated data from the four target trees, Ben2. Lines show standard error.

The fruit size was measured during the last three field visits (27 June, 16 July, 6 August). Here again, no significant difference was noted between the three groups at a significance level of 5%. Only about two-thirds of the variance component was within sub-groups, confirming higher differences between individual trees.

4.4.4 Conclusions

The above mentioned results should be put in relation with the treatments applied (illustration 18 page 35). Apple trees, like most crops, are mainly responsive to nitrogen fertilisation, and to potassium to a lesser extend. Phosphorus rarely plays a role in short-term response. A detailed study of micro-nutrients has been left out of this field trial.

On Ben1's orchard, records indicate that group 3 (conventional) received almost twice as much nitrogen as group 2 and three time as much as group 1 (bio-slurry groups). Potassium levels were roughly similar. However, the results of measurements on shoot terminal length show (although mostly below significance level) an increased growth in groups 1 and 2.

On Ben2's orchard, similar conclusions can be drawn, although here nitrogen and potassium fertilisation was slightly lower on group 3 (conventional). The groups 1 and 2 show increased terminal growth, although again below significance level.

On a qualitative point of view, it has been noted that the leaves treated with bio-slurry seemed slightly lusher. The beneficiaries indicated furthermore that the apple taste was slightly improved on the trees treated with bio-slurry.

To conclude, there is some limited evidence to suggest that bio-slurry, perhaps through its soil application, but more probably as foliar spray, may have contributed to a higher tree fertility. It cannot be said from this study whether bio-slurry would have been effective through its ammonium-nitrogen content, through supplying missing micro-nutrients, or through other biochemical mechanisms.

The reliability of the experiment on apple trees has however been affected by many factors. The recommended fertilisation plans were not put in application by the farmers and the quantities brought to the orchards are not known with certainty. One beneficiary did not use bio-slurry on the soil at all. The orchards were not homogeneous in tree age and size and too little care has been given in choosing similar trees for monitoring purposes, thus exaggerating variance within the groups. The monitored parameters, terminal shoot growth and fruit size, show too much variability within a single tree. If using these parameters, the number of observations should have been significantly increased. Finally, actions by the farmer, in particular the pruning of the shoot tips, may have interfered with the data.

More importantly, and independently of the statistical results of the quantitative monitoring, the results of soil and foliar fertilisation with bio-slurry were not very obvious to qualitative observers, apart perhaps a slightly better colour of the leaves. Therefore, the farmers themselves were left dubious concerning the efficiency of the method. Ben1 argued however that according to him, the bio-slurry had a positive influence on fertility, while he stayed mostly unconvinced of the efficiency against certain pests and diseases.

Another study made on the same two orchards (“Using bio-slurry for pest control”) has concluded that the effectiveness of bio-slurry against pests and diseases could not be significantly observed.

4.4.5 Fertiliser quantities

The government fertilisation station of Zhaotong prefecture recommends a total amount of fertilisers equivalent to 1.1 kg N/tree, 1.2 kg P/tree and 2.7 kg K/tree. However, other sources are far more conservative. For example, Spectrum Analytic (1991), based on a compilation of American extension sources, recommends 225 to 550 g N/tree, 33g P/tree and 125 g K/tree. Phosphorus and potassium can be further reduced or omitted if the soil index is already high. A soil analysis was done in January 2013 on samples of both orchards and concluded that soil P and K levels were already high.

Compared to the literature available on fertilising apple trees, and although important variations exist according to the climate and soil, the recommendations of the fertilisation station as well as the quantities effectively applied by the beneficiaries appear therefore excessively high, especially in phosphorus and potassium. Signs of over-fertilisation can be seen in the length of the terminal shoot growth. According to Spectrum Analytic (1991), nitrogen supply should be adapted as to “obtain an annual terminal growth of 20 to 30 cm”, whether the average lengths in group 3 (no bio-slurry) were 47 cm (Ben1) and 41 cm (Ben2).

Compared to the fertilisation recommendation cited above, it is estimated that the two beneficiaries could save between 1400¥ and 2600¥ per mu, compared to their current purchase of fertilisers. Although this is a purely theoretical projection based on the comparison of different sources of information, it shows the interest of further studying the issues of fertilisation and its possible wastes and excesses.

5 CONCLUSIONS

The experiments described above had to face many challenges during their course: inappropriate terrain (apple), random cooperation/communication with the beneficiaries (apple), choice of inconclusive indicators (apple, corn, potato), undersized statistical groups (apple).

Furthermore, a weakness in the methodology of the experiments consisted in the coupled treatments, in the sense that for each treatment the amounts of bio-slurry varied as well as the amounts of mineral fertilisers. Although experiments in which a part of the fertiliser is replaced by bio-slurry are known to have shown results (Ngo, 2010), early trials should rather focus on keeping the mineral fertiliser supply constant while supplementing some treatments with bio-slurry, as has been done here on the tobacco and potato.

Therefore, many questions on the use of bio-slurry have not been answered with certitude yet. It does however clearly appear that, in the limit of our experimental precision, effects on the crops were difficult to observe. This seriously puts in doubt the idea that using bio-slurry for fertilisation could be an attractive enough incentive to boost the interest of the households in the maintenance and optimal utilisation of their biogas digester.

However, bio-slurry can be used in a variety of ways for fertilisation. In this one year cycle of experiments, only few potential systems could be tested. For example, on corn and potato, bio-slurry has only been experimented in the particular case of its direct use in the planting hole. Results for a top-dressed application may have been very different.

A few results do nevertheless emerge from the experiments, in particular about what not to do. The negative impact of bio-slurry on the germination of potato and on the growth of corn has been shown, when applied in the planting hole. The efficiency of bio-slurry on tobacco was shown, but this advantage is outdone by the negative side-effects on curing . On apple tree, results, although not significant, might hint at a limited efficiency of foliar fertilisation. **It may be wiser, in the light of these results, to restrict the use of liquid bio-slurry to foliar fertilisation and top-dressing established crops.**

A major issue that was faced during the experiment is the one of transport. The beneficiaries have expressed the difficulty of bringing the liquid bio-slurry to distant fields, and seemed to consider the transport not worthy. **It may therefore be better to encourage the use of bio-slurry in the proximity of the house, such as on the vegetable garden.**

Throughout the experiments, various results and comparisons have repeatedly hinted that **over-fertilisation might be widespread in the region** for various crops, including corn, potato, and apple. Working with local farmers on the optimisation of fertilisation levels would reduce economical waste and environmental pollution, but would undoubtedly be a very difficult task, combining tricky data collection, approximate calculations, lengthy field trials and, certainly, resistance from the farming community itself.

Bibliography

DEFRA, 2010. 'Fertilisation manual, 8th edition (rb209)'.

Lennart de Groot, Anne Bogdanski, FAO, 2013. 'Bioslurry = brown gold? A review of scientific literature on the co-product of biogas production'.

Ngo Q.V., 2010. 'Utilization of liquid bio-slurry as fertilizer for green mustards and lettuces in dong nai province'.

Spectrum Analytic, 1991. 'Fertilizing apples'.