The Evaluation of Compost Parameters During Production for the Development of a Potential Yield Model for Phase III Compost

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Abstract: Compost production systems have changed considerably from windrow to bunker phase I, followed by introduction of phase III. Variations in composition of chicken manure and structure of straw can influence formulation. The present study was aimed at identifying a range of the quality parameters, which could identify changes during production due to variations in the composition of raw materials. Monitoring of parameters during phase I, II, III of composting was carried out using 83 batches. Commercial yields harvested from the batches. Optimal parameters for pH, ammonia, total nitrogen, moisture content, ash and C:N ratio were identified. A model for prediction of potential yield of phase III was generated from data set and validated using 10 samples. A new model consisting of the calibration and validation samples explained 81% of variation in mushroom yield (r^2=0.81), with a standard error for calibration of 1.59 kg/m^2. The evaluation of compost parameters during production to optimize substrate quality is discussed.

Key words: Compost quality, phase I. II and III substrate, yield model

1 Introduction

The cultivation of *Agaricus bisporus* requires a selective substrate rich in nitrogen, lignin-humus complex, carbon, inorganic fractions and a dormant microbial biomass.[1,2] Therefore, availability of the important nutrients is essential for mushroom growth and enhancing productivity at phase II or III stages. The main ingredients used by the industry are horse manure, gypsum and wheat straw. As a substitute for horse manure, when its supply is limited, chicken manure is used. Chemical and physical parameters are used for quality control of compost production.[3-6] The parameters that were developed and used routinely included humidity, ammonium N., bulk density and pH in fresh compost, and total nitrogen, ash, and C/N ratio in dried compost. The optimal value for each parameter was identified for the beginning and the end of the composting process.[7-9] It was demonstrated that once compost is produced while these essential parameters are kept in optimal level, highest yields are achieved. In recent years compost production methods have changed. Windrow phase I composting was replaced by bunker phase I, followed by phase II and III, in tunnels.[10-13] The change in production methods created the need to check the parameters for compost quality. Therefore, due to this need, we have developed the optimal values for the above-mentioned parameters, suitable to current production methods.[9, 14]

The use of objective chemical and physical parameters is essential also since the main raw materials for compost production: wheat straw and chicken manure are not uniform. Differences in straw structure occur due to different growing seasons e.g. dry or wet and the spread of the rain during the season, and growing locations e. g. climatic and soil conditions. Differences in chicken manure composition occur frequently due to different conditions in chicken houses, but these are usually minor differences. Substantial changes in chicken manure composition occur once the chicken's diet is altered. With the aid of chemical and physical parameters raw materials analysis were made, and adjustments could be done at the preparation of the initial compost pile. The production stages at phase I, II and III could be monitored for optimal composition and structure and if not, correction measures could be implemented to modify the environmental conditions or the composition of the substrate.

Various models for the prediction of mushroom yield based on phase II microbial, chemical and physical results have been developed,[15-17] but the previous models could not be used for the evaluation of phase III substrates. The changes, mentioned above, in recent compost production practices, created the need to develop new regression models based on the changes in the key parameters during phase I, II and III to predict potential mushroom yield of phase III substrates.

2 Materials and Methods

2.1 Composting

2.1.1 Raw materials

The main raw materials for the production of compost are: wheat straw, chicken manure, gypsum ($CaSO_4$) and soybean meal.

Wheat straw: Straw used in the trials was a mixture of new season and old straw delivered in 450-500 kg size bales. The material is sampled before wetting, after wetting prior to bale opening and also at the bale opening stage during mixing of the ingredients.

Chicken manure: The composition of the chicken manure from the broiler industry were analysed regularly and average dry matter and nitrogen content ranged between 70-85% and 4-5% respectively. The manure was stocked under cover for 1-2 weeks before use. Samples were taken from several places of the manure pile, on arrival to the composting yard and before entrance to the mixing line. The samples were measured for moisture content, total nitrogen dry matter and ash content.

Composting water: The water, used in the production batches for wetting the straw bales and compost piles, was waste-water collected from the composting process and this is widely known as "goody water". It was permanently aerated to minimise anaerobic conditions and the development of reduction products causing bad odour. During the trials, samples were taken from their reservoir and the ammonium-N content was measured.

Gypsum: Gypsum used in the production batches was a by-product from the fertiliser industry. The gypsum received in bulk was stocked in the yard for drying and elimination of acid residues by evaporation.

2.1.2 Mixing

Mixing of the raw materials was achieved in a mechanised production line, where the raw materials were mixed at a ratio of 1000 kg straw; 500 kg chicken manure; 110 kg gypsum; 50 kg soybean meal. Only 80% of the chicken manure and gypsum were introduced during initial mixing, and the rest introduced during the later stage of phase I. The soybean meal (50 kg) was added in the production line during phase I. The blended raw material pile was sampled from five different areas immediately after mixing. The five sub-samples were combined and the following parameters were measured: moisture content, pH, and ammonium-N content and total nitrogen.

2.1.3 Bunker composting (phase I)

The raw compost was transferred to an open bunker of 50 × 4 × 8 m dimension for a period of 14 days using a bunker-filling machine, (Hoving Holland, Ohmweg Staadkanall, The Netherlands) and re-mixed every 4-5 days. During this period, 10-20% of the chicken manure, gypsum, all the soy-bean meal and water were added

during mixing. Samples were taken randomly from the pile, at different locations and depth, also after every turning (3 times) and during pile preparation. All samples were assessed for moisture content, pH, total nitrogen and ammonium-N content.

2.1.4 Phase II

On completion of phase I, the substrate was transferred to tunnels for pasteurisation and conditioning for seven days. The substrate was sampled at filling and emptying of the tunnel. Samples from different areas and depth of the tunnel were analysed for moisture content, pH, ash, total nitrogen and ammonium-N.

2.1.5 Growing rooms

Samples from the "green" compost and phase II on shelves in the mushroom growing rooms were taken from five different positions on the shelves to prepare a combined sample for each room. The samples were tested for moisture content, pH, ash, total nitrogen and ammonium-N content.

2.1.6 Phase III in tunnels

This phase can last for a period of 16-17 days. Five sub-samples along the tunnel at different depths were taken and the materials were blended to form a composite sample, at filling and emptying the tunnel. The measured parameters include moisture content, pH, ash, total nitrogen and ammonium-N.

2.1.7 Phase III in growing rooms

Phase III in the growing rooms can last for 16 days. The compost was sampled from the shelves at filling and at the end of this phase. Sub-samples were taken from the centre of the shelves at different heights. The measured parameters of the composite samples were moisture content, pH, ash, total nitrogen and ammonium-N.

Since the introduction of the new composting technology, some growers still take delivery of phase I compost and continue the process on the farm at a fill rate of 130-140 kg/m^2. Other growers use phase III compost. For this investigation, growers of both types were chosen. Therefore, we have followed phase II and III parameters both in tunnels of central production site and also in growing rooms. The model was developed mainly on the yield results of a grower who was supplied with phase I compost. Spawn was mixed at a rate of 7-10 litres to 1. 0 tonne of phase II compost. The casing used was prepared with Irish peat (Harte-Peat, Ireland). The management of growing conditions were adapted as recommended by the spawn producer. The strains used in the trials were A15, 737 and 608 (Sylvan, International).

2.2 Chemical and physical analysis

2.2.1 Sample preparation and analysis

Ten grams of the wet sample were suspended in 50 ml distilled water and mixed for 30 minutes followed by pH measurement using A_{420} pH meter (EL - Hama, Israel). Ammonia (ammonium-N) was measured using Ammonium-Test kits (1.11117.0001Merck, USA). The moisture content was measured gravimetrically by drying the sample overnight to constant weight in an oven at 105° C. Total nitrogen (NDM) is analysed by the Kjeldhal method[18] on dried and milled (Retsch SM100 mill) samples.

2.2.2 Wheat straw analysis

Wheat straw samples were divided into two categories: long straw (new straw) and short straw (old straw). From each category, five samples (50 gm) were collected randomly from the bale. Each sample was divided into groups according to stem length, and average length was calculated for each set of samples representing the straw stock. The water absorbing capacity of the straw was measured using the 50 gm samples by immersing in water for 15 minutes. The materials were taken out of the water and left for one minute for the residual water to drain. The samples were weighed and the volume of absorbed water was calculated based on the previous dry weight of the straw.

2.2.3 Chicken manure analysis

Samples from all deliveries of chicken manure were analysed for moisture content and total nitrogen content. The proportion of chicken manure used in the formulation of raw materials was calculated and adjusted according to these parameters.

2.2.4 Analysis of results

The analytical and yield results of the sample population were evaluated by employing principal component analysis (Unscrambler software package, version 7.6, CAMO, Trondheim, Norway) to assess the changes during the three production stages. The measured results were regressed against mushroom yields obtained from the grower, using partial least squares regression method (PLS). The leverage, outlier detection and ratio of calibrated to validated explained variance, ratio of validated to calibrated explained variance and total explained variance limits during the calculation were set at 3.0, 3.0, 0.5 and 0.75 and 20% respectively. The calibration based on the chemical results was developed from 83 commercial trials and the regression equation was validated using recent results obtained from 10 production tests.

3 Results and Discussion

The composition of the raw materials and wastewater used in the production trials was monitored to assess formulation of the ingredients and due adjustments were made based on the results of the tests. In order to identify the optimal parameters for the production of synthetic compost, analyses of 83 piles were carried out during 2002-2004. Yields of mushrooms from different piles were recorded. Linear regressions between yields and chemical parameters were used to determine the optimal values for each parameter. The identified optimal parameters are presented in Table 1. During 2002-2004, straw quality was good but, since the summer of 2004, straw quality (as indicated by thin cell-wall structure) declined considerably due to insufficient rain near the end of growing season. Poor quality straw degrades rapidly mainly due to lower structural hemicellulose and lignin content,[6] and the physical structure or bulk density of composts needs to be conserved during the production. In order to maintain the quality parameters, adjustments were made in the optimal parameters, which included lowering of moisture content, total nitrogen and ammonia concentrations and also duration of the stages.

The use of adjusted parameters enabled substrate production to continue with only a minimal reduction in yield. On the basis of these results, we concluded that optimal chemical parameters for compost quality should be adjusted to match input straw quality for minimising reduction in substrate quality. Composters should regularly assess straw characteristics, as a starting point before finalising formulations and protocols should be modified as and when necessary.

Table 1. Optimum quality parameters recommended for utilising high quality straw (HQS) and poor quality straw (PQS) during production of phase I, II and III compost

Parameter	Phase I HSQ	Phase I PSQ	Phase II HSQ	Phase II PSQ	Phase III HSQ	Phase III PSQ
Moisture (%)	73.5 - 74.5	71.5 - 72.5	66 - 68	65 - 67	64 - 66	62 - 64
pH	8.1 - 8.2	8.0 - 8.1	7.5 - 7.7	7.6	6.3 - 6.5	6.4
Ammonia (ppm)	750 - 950	650 - 850	50 - 100	50	-	-
Total nitrogen (%)	1.7 - 1.9	1.5 - 1.7	1.9 - 2.1	2.0	2.1 - 2.3	2.2
Ash (%)	25.0 - 29.0	27	27 - 32	29.5	29 - 35	32
C:N ratio	21 - 26	23 - 28	14 - 16	15	12-15	13.5
Bulk Density (kg m3)	570	580	-	-	-	-

3.1 Calibration

Table 2a shows the range, mean values and standard deviations of the key parameters of phase I, II and III compost of the calibration sample set The measured parameters were centred prior to analysis and regressed against grower yields using partial least squares method. Out of the 83 calibration samples, 17 samples were excluded due to incomplete analysis of the parameters or no yield results or errors in the measured values and only 66 samples were used in the development of the calibration. A model based on all key parameters explained 86% of the variation in mushroom yields ($r^2 = 0.86$) of the calibration sample set (Figure 1). The standard error for calibration (SEC) was 1.64 kg/m^2 and standard error for cross validation (SECV) of the model using the same sample population was 1.92 kg/m^2 ($r^2 = 0.80$).

The regression co-efficient values of the parameters are presented in Figure 2 to show negative or positive influence to the calibration model. Among the factors listed in the figure, ash and C:N ratio were the most significant parameters with a positive impact to the model, followed by pH, moisture content and total nitrogen, which influenced the model negatively indicating that some of these factors could be inhibitory or toxic to the microorganisms at higher concentrations.

This outcome is not surprising, as ash content and C:N ratio determine availability of inorganic and organic fractions in the substrate. The degree of variability of the substrate at Phase I stage is high and as homogeneity of the substrates improves at phase II and III stages, the importance of the key parameters in determining quality of compost should advance significantly.

Table 2. Comparison of minimum and maximum range with mean values and standard deviation (SD) of phase I, II and III compost parameters of (a) the calibration and (b) validation sample sets, carried out during 2002 and 2004

(a) Calibration set: sampling period May 2002 - early 2004

	pH Phase I	Moisture (%) Phase I	Ammonia (PPM) Phase I	Total Nitrogen (%) Phase I	Ash (%) Phase I	C:N ratio Phase I	pH Phase II	Moisture (%) Phase II	Moisture (%) Phase III	Yield (kg/m^2) Phase III
Minimum	7.77	70.00	500	1.39	26.48	22.40	7.36	62.80	59.05	18.70
Maximum	8.38	75.10	1325	2.10	34.43	32.60	7.95	71.50	69.19	37.80
Mean	8.13	72.81	800.43	1.82	29.88	26.14	7.64	67.10	64.63	28.46
SD	0.11	1.06	152.04	0.17	2.62	2.29	0.15	1.68	2.01	3.61

The mushroom yields were obtained from a grower especially selected for this trial.

(b) Validation set: sampling period June 2004 - Oct 2004

	pH Phase I	Moisture (%) Phase I	Ammonia (PPM) Phase I	Total Nitrogen (%) Phase I	Ash (%) Phase I	C:N ratio Phase I	pH Phase II	Moisture (%) Phase II	Moisture (%) Phase III	Yield (kg/m²) Phase III
Minimum	7.77	71.5	750	1.39	28.245	24	7.52	62.8	59.05	28.90
Maximum	8.16	73.77	1325	1.59	34.43	29.2	7.81	68.45	64.10	31.80
Mean	7.99	72.37	925.59	1.47	32.14	26.92	7.71	64.91	60.70	30.36
SD	0.11	0.78	173.19	0.07	1.8	1.71	0.10	1.64	1.66	0.90

3.2 Validation

The validation of the PLS model was carried out using independent samples obtained from 10 commercial production batches. The range, mean and standard deviation of the measurements are shown in Table 2b. The

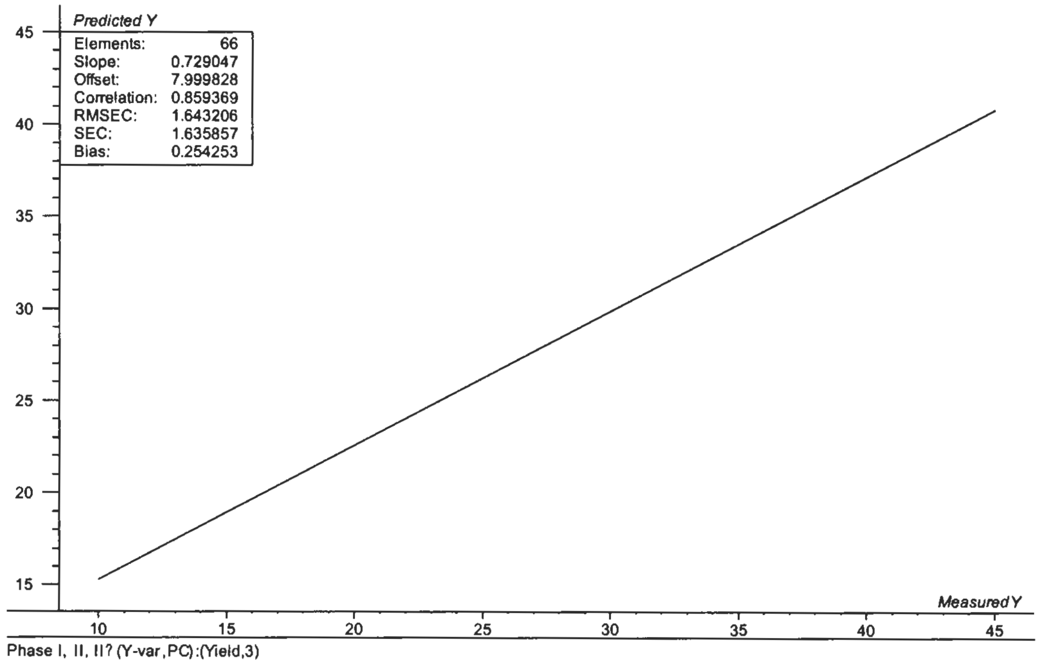

Figure 1. The relationship between phase I, II and III key parameters and grower yields of production trials (calibration sample set) carried out in 2002-04

(R^2 for calibration = 0.86, with a SEC value of 1.64 kg/m² and R^2 for cross-calibration = 0.80, with a SECV value of 1.92 kg/m²).

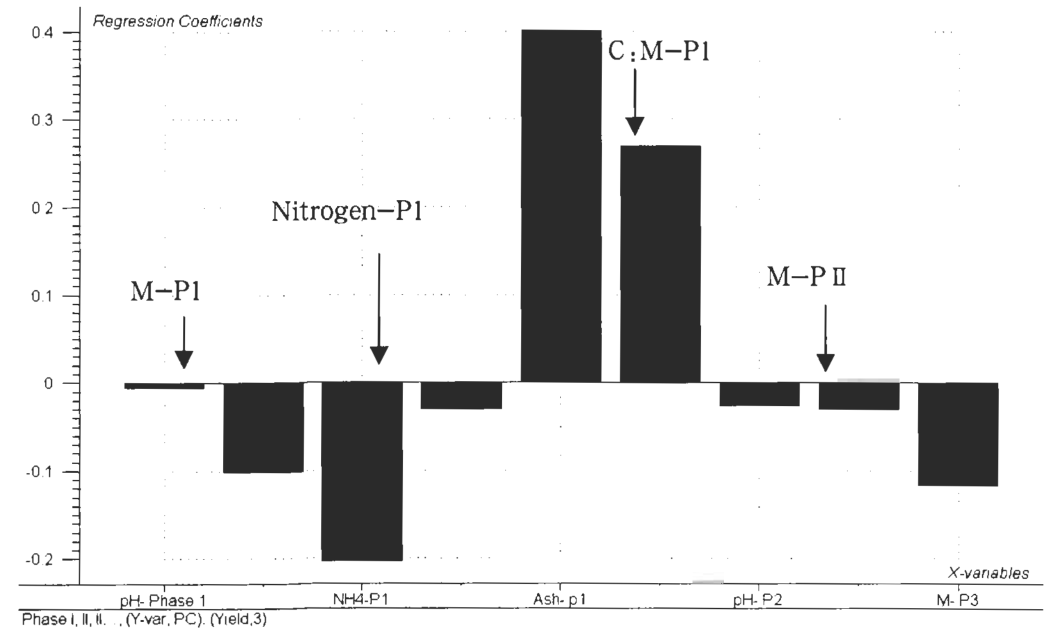

Figure 2. Positive and negative regression co-efficient values for pH, moisture content (M, %), ammonia (ppm), total nitrogen (%), ash (%), C:N ratio of phase I (P 1), pH and moisture (%) of phase II (P II) and moisture content (%) of phase III samples showing influence of the parameters to the model

model predicted productivity of the 10 compost samples with a standard prediction error (SEP) of 1.29 kg/m² and r^2 = 0.6, indicating an acceptable correlation between predicted and measured mushroom yields of the ten samples (Figure 3). The SEP value as a percentage of the mean yield is acceptable to growers and researchers, although this can be improved with a better and bigger data set.

The mean predicted yield of the 10 compost samples was 30.36 kg/m² compared to a mean trial yield of 30.29 kg/m². Of the 10 composts, the PLS model predicted yields of all the test composts accurately, except for Pile no 699, which was predicted with an error of 2.7 kg/m². The model described this sample poorly, as indicated by the high SEP compared to the mean SEP of 1.29 kg/m² (Figure 3). The R^2 for validation improved to 0.74, when pile no 699 was excluded from the validation set and the mean SEP for the 9 samples was reduced to 0.9 kg/m².

The accuracy of the reference method used to measure the parameters will affect the performance of the PLS model to predict potential yield. The predictive power of a model can be impaired by complex parameters, such as productivity, which is dependent on the production process, the spawn, casing and the management of crop. The potential yield, which is independent of cultural factors, is probably governed by the interaction of pH, dry matter, nitrogen dry matter, carbon, hydrogen, ammonia, ash and minerals.[17] The effect of either an individual parameter or interaction of parameters cannot be determined to the exclusion of effects from other parameters. Therefore, it is very unlikely that even close to 100% of the yield differences will ever be explained, due to variation in compost quality during production.[17] The results of the experiments indicated that potential mushroom yield obtained under standard cultural conditions could be predicted. However, a much larger sample population with accurate yield data would be required to develop the model for commercial use. The model may have to be modified to suit the growing conditions prevailing in commercial mushroom houses and grower expertise.

4 Conclusion

A new PLS model was generated from the calibration and validation sample sets, showing a correlation of r^2 =

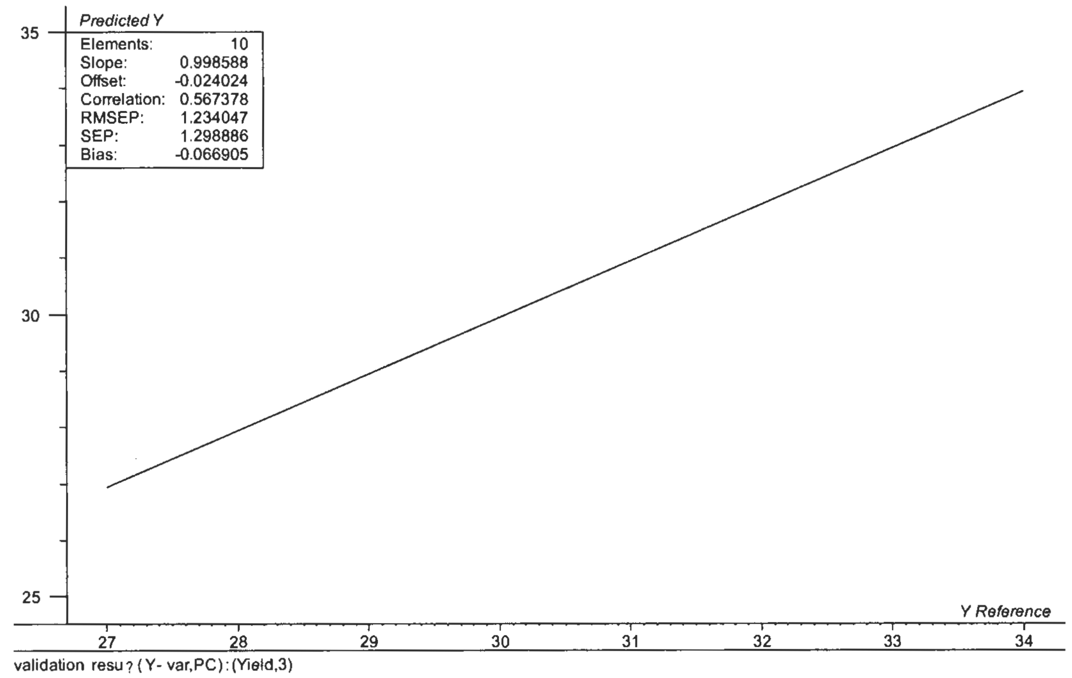

Figure 3. Validation of the Phase I, II and III model using 10 production trials carried out in 2004; the model predicted yields of the samples with a mean SEP of 1.29 kg/m², R^2 = 0.6, slope = 0.99 and bias = -0.06; compost pile no 699 (ringed) was poorly predicted by the model with a higher SEP of 2.7

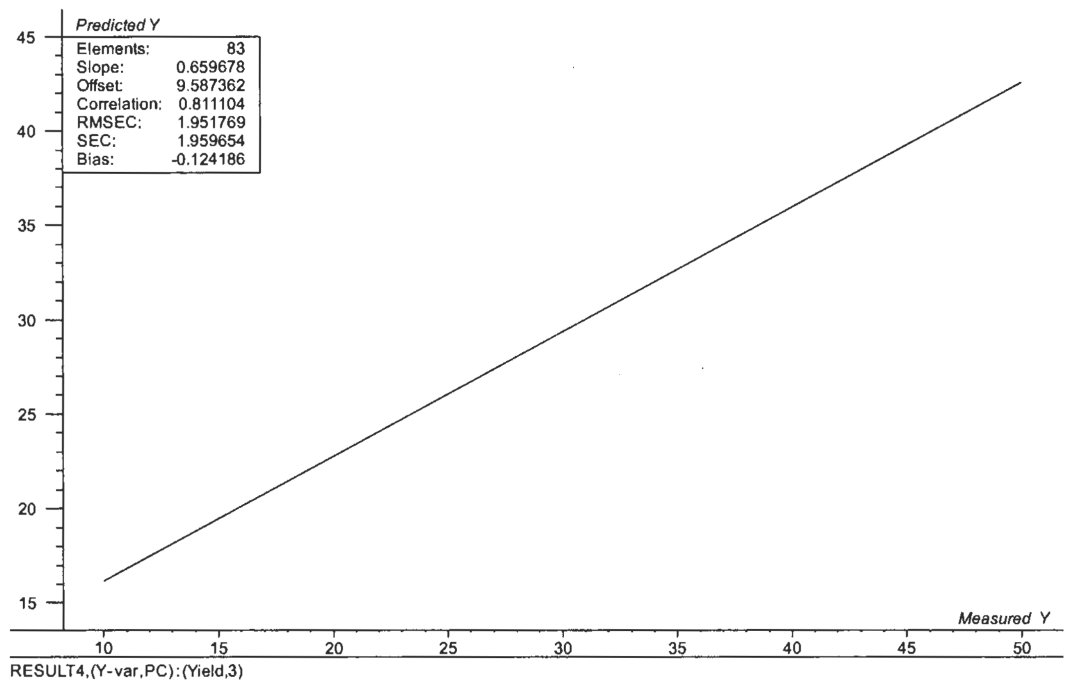

Figure 4. A PLS model of the phase I, II and III key parameters and yield of both the calibration and validation sample sets carried out in 2002-04

(R^2 for calibration = 0.81, with a SEC of 1.9 kg/m² and R^2 for cross-calibration = 0.76, with a SECV of 2.0 kg/m²).

0.81 and calibration error of 1.9 kg/m² (Figure 4). The new equation is less accurate than the previous model and this may be due to poor straw used in the production of the validation sample set or other unknown factors. The development of a best equation will require the evaluation of data processing techniques, monitoring the performance of the equation and re-calibration, when necessary. The equations developed may be able to predict potential yield of compost prepared in other countries. The accuracy of the predictions could be enhanced by including other important parameters, such as fibre fractions, available water- soluble polyphenols and carbohydrates, which were not analysed for the sample sets, and also by expanding the calibration database with selected samples.

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