Case study 16: Influence of planting date and organic fertilisation on growth, yield and corm quality of South African taro landraces

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Summary

Taro is an important crop to subsistence farmers because of its potential to alleviate food insecurity, and, in KwaZulu-Natal, South Africa, it is a recently-discovered cash crop by the mainstream food market. Different taro landraces have different agronomic, nutritional and morphological characteristics. Producers and marketers of taro are interested in knowing which landrace is the best in terms of yield, storability and food quality. With this aim in mind studies were designed to determine taro growth in relation to yield, corm crisping quality, mineral content and storability. This case study shows how a strategy for undertaking this research was developed and describes the different studies undertaken during the research process.

A field trial was carried out at two locations and designed as a factorial split-plot field experiment to compare the effects of planting date and rate of application of organic fertiliser on

plant growth, corm yield, corm crisping quality and mineral content of three taro landraces. Taro is grown at different subsistence farming locations in South Africa. Comparison of performances at the two locations was of interest to the researchers to assist with their advice to farmers and extension officers. In a second study corms of the three landraces, harvested from one of the locations and the first two planting dates, were packaged in three different ways and stored at two different temperatures to assess their quality after storage for four months. A third study was included to study the performance of first generation corms on their emergence and stand establishment.

Methods of study design are described for each of these studies and methods of factorial statistical analysis and reporting demonstrated for one of the field trials.

Glossary

Some terms with which the reader may not be familiar

Gromor Accelerator: the organic fertiliser used in the study.

Landrace: domesticated plant adapted to the natural and cultural environment in which it originated and often developed naturally with minimal assistance or guidance from humans using traditional breeding methods.

Organic fertiliser: fertiliser composed of naturally occurring compounds and manufactured through natural processes (such as composting or naturally occurring mineral deposits).

Background

Taro (Colocasia esculenta (L.) Schott) is a traditional crop that has a potential to alleviate food insecurity, reduce poverty and create employment in the developing world. Taro is grown in a range of subtropical coastal areas in South Africa, starting at Bizana district in the Eastern Cape and as far as the coastal area of KwaZulu-Natal. The crop is also cultivated in the subtropical and tropical parts of Mpumalanga and Limpopo provinces. However, Umbumbulu, an area close to the KwaZulu-Natal coast, where farmers are members of EFO (Ezemvelo Farmers Organisation), is the only area in South Africa where subsistence farmers have been able to grow certified organic taro for the formal market. Woolworths and Pick'n Pay sell the taro that the farmers produce in Durban, Cape Town and Johannesburg.

There is now an interest in processing taro into crisps, and this would provide more opportunities for the marketing of taro. Farmers from inland areas are also becoming interested in growing taro in view of the increasing popularity of taro as a cash crop. One problem is that 'dryland' or 'rainfed' taro (i.e. grown without irrigation) does not grow in winter; consequently it is available for harvesting only from late February to early July. An additional problem is that taro has a short shelf-life.

There are different landraces of taro. A participatory study was done for a Masters degree (Mare, 2006) to investigate the landraces that were most preferred among farmers in Umbumbulu, and the three, namely, Dumbe-Dumbe, Mgingqeni and Pitshi, most favoured for marketing, were identified. These taro landraces have different agronomic, nutritional and morphological characteristics (Mare, 2006), and so producers and marketers need to know which landrace is best in terms of yield, corm crisping quality, food quality and storability. It is also possible that different landraces differ in terms of climatic requirements and so may vary in terms of optimal planting dates and fertiliser requirement.

Dumbe-Dumbe (left) Mgingqeni (right)

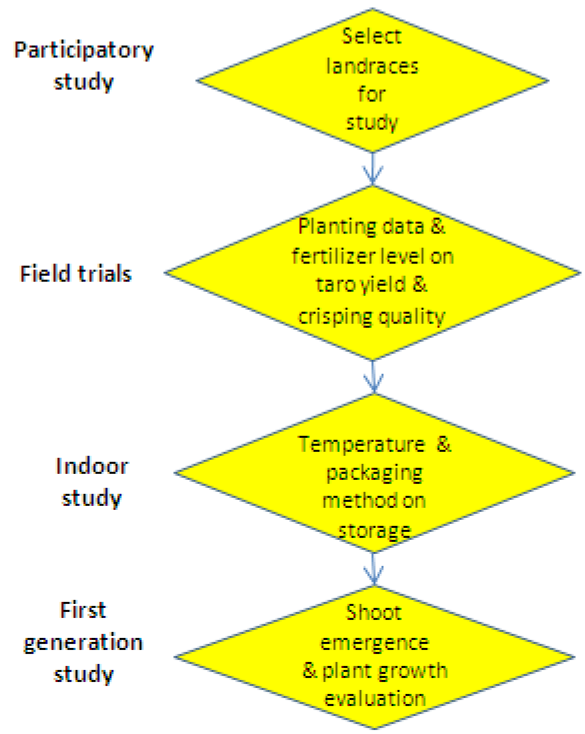
Pitshi (source: Rorisang Mare)

Research strategy

Before developing a research strategy one needs first to consider the agronomic, nutritional, morphological and quality characteristics that subsistence farmers, processors and consumers look for:

- Farmers need taro landraces that produce high yields and can be stored as long as possible (the crop tends to have a short shelf life).
- Processors prefer large corm taro landraces of superior quality for crisping (high specific gravity, high starch content, low reducing sugar content, low alpha amylase activity and high calcium content).
- Consumers need to benefit from a nutritious product based on the extent to which minerals provided by taro landraces contribute to the human diet.

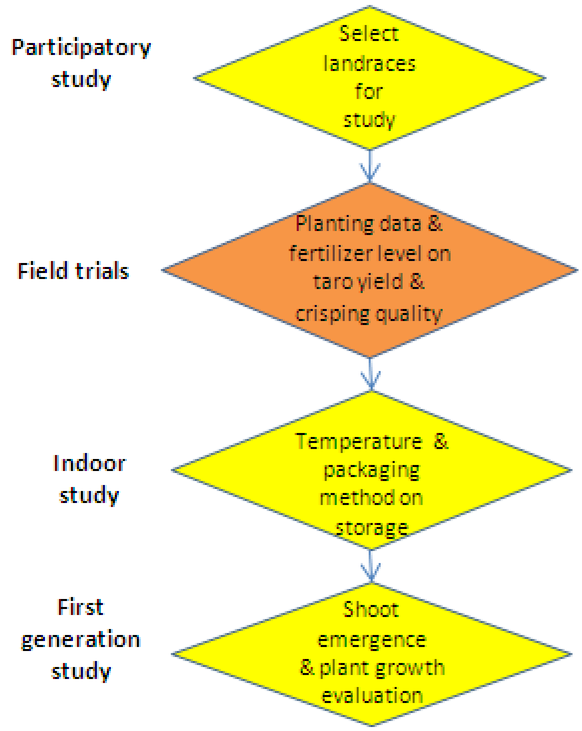
A series of experiments were thus planned to compare taro landraces in terms of yield, mineral content, suitability for crisp making and length of storage. The research process was set out as three consecutive studies. The flow chart alongside also includes the participatory study already mentioned that was necessary to establish the three landraces to be used in the study. The other three studies will be described as Studies 1, 2 and 3.



Study 1

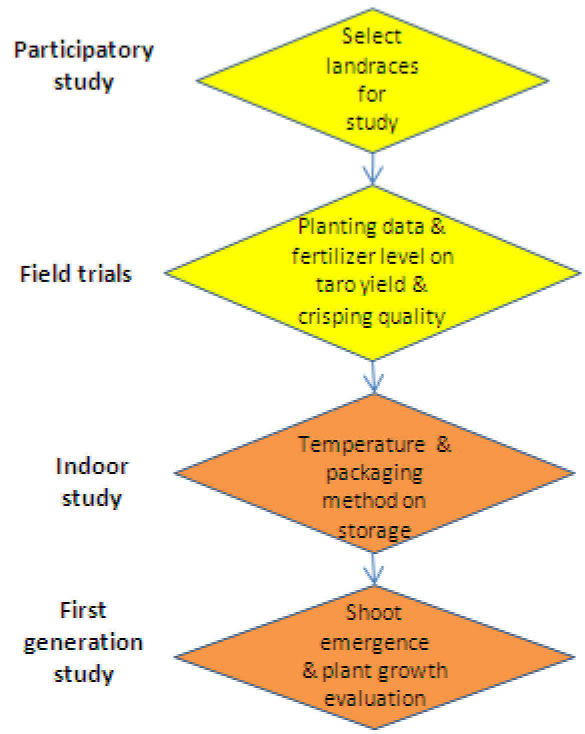
The first step was to carry out field trials to determine planting date and organic fertiliser effects on plant growth, yield, mineral content and corm crisping quality of taro corms. It was of interest to compare performance across different locations in order to advise farmers and extension officers of the suitability of different landraces in different environments. The experiment was therefore replicated in two locations to provide indications of potential genotype x environment interactions.

Two field studies were planned – one at Umbumbulu (29^0 36'S 30^0 25'E) and one at Ukulinga (University of KwaZulu-Natal Research Farm) (29^0 37'S 30^0 16'E). Ukulinga was chosen as the second site in order to represent an inland area where increasing interest in the growing of taro is being shown by farmers. Each trial was planned as a split-plot design. The crops were to be planted on different dates as main plots with factorial arrangements of fertiliser and landrace as sub-plots randomised within planting date.



Study 2

Using corms harvested from the first study a second study was then to be undertaken under laboratory conditions to compare storage qualities for the three landraces under different temperature regimes (12^0C in a cold room or ambient temperature in a store room) and alternative methods of packaging (polyethylene bag, box or mesh bag). Samples of corms would be selected from those grown in Study 1 with each level of fertiliser to see whether organic fertiliser influenced storage quality under the different temperatures and packaging methods.



Study 3

Finally, a third study would be needed to see how well first generation corms perform in terms of shoot emergence and subsequent plant development: plant height, number of leaves, leaf area, number of suckers and overall above ground biomass. Again corms would be selected from each landrace x fertiliser level combination in Study 1.

Objectives

The objective for the whole study was formulated after consideration of the research strategy. It was:

- To assess the qualities of three taro landraces, namely Dumbe-Dumbe, Mgingqeni and Pitshi, in terms of plant growth, yield, mineral content, suitability for crisp making and storage, and to recommend the landrace that is most suitable for the formal market.

Each study had its own separate objective:

Study 1: To determine effects of date of planting and level of organic fertiliser on plant growth, yield, corm crisping quality and mineral content of taro corms from three landraces: Dumbe-Dumbe, Mgingqeni and Pitshi.

Study 2: To determine effects of temperature and packaging on storage quality of corms from three landraces (Dumbe-Dumbe, Mgingqeni and Pitshi) in terms of level of carbohydrate (sucrose, glucose, fructose and starch concentration) and also on any emergence of new shoots or roots.

Study 3: To determine the performance of first generation corms from three landraces (Dumbe-Dumbe, Mgingqeni and Pitshi) in terms of shoot emergence and plant development (plant height, leaf number, leaf area, number of suckers and overall above ground biomass).

Questions to be addressed

By confining ourselves to just two yield measurements (dry corm weight and number of corms) recorded in Study 1 we shall

- determine the best month for planting each of the three landraces
- decide which one is the most suitable landrace to be grown by farmers for the formal market
- and determine the optimum level of fertiliser for growing this landrace.

We shall discover that delaying planting until January resulted in several plots with zero growth. We shall discuss how these missing values should be treated.

Finally, the design of Study 1 provides an example of a split-plot factorial experiment. We shall show

- how to analyse and report the results from such an experiment
- how to evaluate the basic assumptions for analysis of variance

Study design

Study 1

A split-plot field experiment was designed at each site (Umbumbulu and Ukulinga) to compare the effects of planting date and organic fertiliser level on growth, yield, corm crisping quality and mineral content of the three taro landraces. The landraces were planted on four dates: October 2007, November 2007, December 2007 and January 2008, randomised across main plots. Each experiment had three replicates of main plots. Factorial combinations of landraces (Dumbe-Dumbe, Mgingqeni and Pitshi) and levels of organic fertiliser (Gromor Accelerator) (0, 5330 and 10660 kg ha $^{-1}$) were randomised across sub-plots. Gromor Accelerator nutritional composition is as follows:

N	P	K	Mg	Ca	S	Fe	Cu	Zn	B	Mn	Mo
(g kg^{-1})						(mg kg^{-1})					
30	15	15	5	20	0.6	2000	40	250	40	400	4

Soil samples were collected and analysed before the start of the experiment and the amount of organic fertiliser to be applied in each experiment was calculated based on these results. The soil was sampled from the top 30 cm to represent the zone that contains the roots of the plant and a grid was used to collect a set of representative samples. Some of the results of analyses are shown below.

Site	pH (KCl)	Sample density (g ml^{-1})	Exch. Acidity (cmol L^{-1})	Total cations	P	K	Ca	Mg	Zn	Mn	Cu
					(mg L^{-1})						
Ukulinga	5.07	1.08	0.05	25.22	10	223	2780	1303	4.6	27	7.1
Umbumbulu	4.16	0.96	1.68	6.72	3	97	658	183	1.3	8	5.4

Rainfall and temperature data were obtained from Weather South Africa for the duration of the experiments.

The field plan is now shown.

The letters D, M and P refer to Landraces Dumbe-Dumbe, Mgingqeni and Pitshi, respectively and are followed by 0,1 and 2 referring to the level of fertilizer. **Block 1**

Planting date									
January	1 P1	2 D1	3 M2	4 P0	5 M1	6 P2	7 D2	8 D0	9 M0
December	18 D2	17 M1	16 D1	15 M0	14 M2	13 P0	12 P2	11 P1	10 D0
October	19 P1	20 P0	21 M0	22 M2	23 P2	24 D2	25 D0	26 M1	27 D1
November	36 D1	35 P1	34 P2	33 P0	32 D2	31 M0	30 M1	29 M2	28 D0

The same plan was used at each site. Plot size was 4m2 and each plot contained 16 plants planted 4 x 4 and spaced 0.5m apart. Plots were separated by 0.5m. **Block 2**

Planting date									
November	37 D0	38 M1	39 D2	40 P0	41 M2	42 P2	43 P1	44 M0	45 D1
December	54 D1	53 M2	52 M1	51 D2	50 P2	49 M0	48 P0	47 D0	46 P1
October	55 P2	56 D1	57 M1	58 M2	59 D0	60 P0	61 M0	62 P1	63 D2
January	72 P2	71 D0	70 D2	69 P0	68 D1	67 P1	66 M2	65 M0	64 M1

Note how the plot numbers are arranged: from left to right in one row and in the reverse direction in the next row. This is discussed under Data Management. **Block 3**

Planting date									
November	73 D0	74 P0	75 M0	76 P1	77 D2	78 M2	79 P2	80 M1	81 D1
January	90 D2	89 P1	88 M0	87 P0	86 P2	85 D0	84 D1	83 M2	82 M1
December	91 P0	92 D2	93 M2	94 P1	95 P2	96 M1	97 D1	98 M0	99 D0
October	108 M0	107 D0	106 P1	105 D2	104 M1	103 M2	102 P2	101 D1	100 P0

The skeleton ANOVA table is as shown.

Source of variation	df
Replicate	2
Date of planting	3
Residual	6
Landrace	2
Fertiliser level	2
Date x Landrace	6
Date x Fertiliser level	6
Landrace x Fertiliser level	4
Date x Landrace x Fertiliser level	12
Residual	64
Total	107

The trial at Umbumbulu was run under the conditions in which the farmers were already engaged. Sowing was done by hand on ploughed and harrowed fields. A hand-hoe was used to make each hole, organic fertiliser was mixed with the soil and one corm was planted in the hole. Weeds were controlled by hand hoeing once a month. Farmers were involved throughout the study from soil preparation to harvesting.

The trial at Ukulinga was run as for Umbumbulu with the exception that field workers at Ukulinga from the UKZN Experimental Research Farm assisted with the field work, e.g sowing, hand hoeing and harvesting.

Corm sizes vary both among and within landraces. The corms used for this study were in the following size ranges: 21 – 60g for Dumbe-Dumbe, 11 – 40g for Mgingqeni and 5 – 20g for Pitshi. The corms for Mgingqeni and Pitshi were harvested at Ukulinga in 2007 and those for Dumbe–Dumbe were obtained from farmers in Umbumbulu.

The numbers of plants that emerged per plot were counted and emergence percentages calculated at monthly intervals until no other plants emerged.

Data on plant height, leaf number and leaf area were collected every month for four months from the four innermost plants in the plots. These data were averaged to calculate mean plant height, number of leaves per plant and total leaf area per plant. Leaf area was determined according to Modi (2007). When one or more of the four central plants did not emerge any four plants were selected from the plot. Should fewer than four plants emerge in the whole plot then the average of those that had emerged was recorded.

Yield at maturity was determined by harvesting all corms from the four innermost plants, weighing the total fresh weight, counting the total number of corms and calculating the average to determine the total number of corms and total fresh weight per plant. Fresh corms were also weighed individually, classified into different weight classes and their mean specific gravity and dry corm weight recorded. Corms were freeze-dried at harvest for starch content, sugar content, alpha amylase activity and mineral content determination.

The crop planted first (in October) was considered mature when all above ground biomass had died off for the first planting; maturity was subsequently defined at four week intervals for the subsequent plantings.

Study 2

The second study was undertaken as a split-split-plot design to determine effects of temperature and packaging on the storage quality of the corms. One cold room (12^0C) and one store room (ambient temperature) were available for the experiment. Corms harvested from the planting in October at Ukulinga were used.

Replicate 1										
12°C	Polyethylene	1 D1	2 M2	3 P0	4 M1	5 D0	6 P2	7 D2	8 P1	9 M0
	Mesh bag	18 M0	17 P1	16 D1	15 P2	14 M2	13 D2	12 M1	11 D0	10 P0
	Box	19 D2	20 M1	21 M0	22 D0	23 P1	24 M2	25 P0	26 P2	27 D1
Ambient	Mesh bag	36 M0	35 P0	34 D1	33 M2	32 P2	31 D0	30 M1	29 D2	28 P1
	Polyethylene	37 D2	38 M1	39 P2	40 D1	41 P1	42 M0	43 P0	44 M2	45 D0
	Bag	54 M2	53 D0	52 P0	51 M0	50 D2	49 P2	48 D1	47 P1	46 M1

Twenty four corms were collected from each sub-plot in Study 1 and the three replicated sub-plots for the same landrace x fertiliser level combined together to give a total of 72 corms per group. Eighteen boxes were obtained in order to provide three replicates for the experiment. Polyethylene bags were put into six of them, mesh bags put into six others and the remaining six were left empty. Groups of four corms from each landrace x fertiliser level combination were laid in each box in a predetermined factorial design for each of the six boxes (as shown for replicate 1) and the group labeled. Nine boxes (three with a polyethylene bag, three with a mesh bag and three without either) were placed in the cold room. The other nine boxes were put into the store room.

One corm from each group within each box was removed each month over a period of four months. The corm was cut in half; one half was peeled and freeze dried for starch and sugar analysis while the other half was used for determination of specific gravity and dry matter content.

The numbers of corms that showed signs of shoots or roots sprouting were also counted each month.

Cold room (12^oC) and store room (ambient temperature) can be considered as main plots, packaging methods (polyethylene bag, mesh bag or box alone) as sub-plots and factorial combinations of organic fertiliser and landrace as sub-sub plots. Within each of the cool and store rooms packaging method was replicated three times.

The skeleton analysis of variance table is shown here for each monthly sampling time. Strictly speaking the replication term should appear at the subplot level. We cheat slightly by pretending that we used three separate cold rooms and three separate store rooms. In this way the replication term is represented at the main plot level.

Source of variation	df
Temperature	1
Replication within temperature	4
Packaging	2
Temperature x Packaging	4
Residual	8
Landrace	2
Fertiliser level	2
Temperature x Landrace	2
Temperature x Fertiliser level	2
Packaging x Landrace	4
Packaging x Fertiliser level	4
Landrace x Fertiliser level	4
Temperature x Packaging x Landrace	4
Temperature x Packaging x Fertiliser level	4
Temperature x Landrace x Fertiliser level	4
Packaging x Landrace x Fertiliser level	8
Residual	102
Total	161

Study 3

Additional corms from each of the three fertiliser x landrace groups grown at Ukulinga were stored in the 12^0C cold room polythene bags for four months (the duration of Study 2). These were used in this study to assess the performance of first generation corms. Corms were planted in pots, one corm per pot, in a shade house and placed in a randomised block design with nine landrace x fertiliser level combinations replicated three times (nine pots per replicate) to account for environmental variations within the shade house.

Seed corms were weighed before planting. Pots were examined daily and the day when shoot emergence occurred recorded. Plant height, leaf number, leaf area, number of suckers and above ground biomass (both fresh and dried) were recorded 33 days after planting when first plants reached the three leaf stage.

This study is not considered further in this case study.

Source material

A number of data sets are provided to accompany this case study. CS16Data1a contains final crop yield and mineral composition data etc. collected in the Ukulinga field experiment and CS16Data1b data for the Umbumbulu field experiment (Study 1). CS16Data1c and CS16Data1d contain monthly data on plant performance respectively at the two sites. Data collected during the storage experiment (Study 2) are stored in CS16Data2.

Only the data set CS16Data1a will be used to illustrate the methods of analysis. The other data sets are provided for use in some of the Study questions.

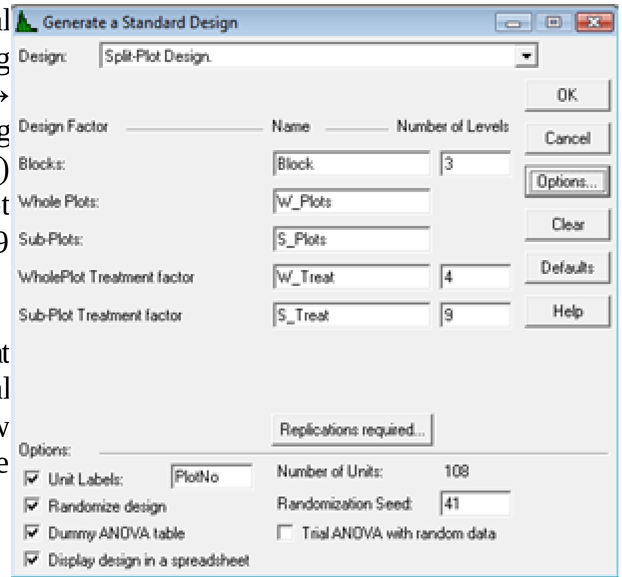
Some of the variables originally recorded in the experiments have been excluded to simplify the data sets for the purposes of this case study. Thus, several of the mineral composition variables are omitted from CS16Data1a and CS16Data1b. CS16Data2 contains just measurements for specific gravity.

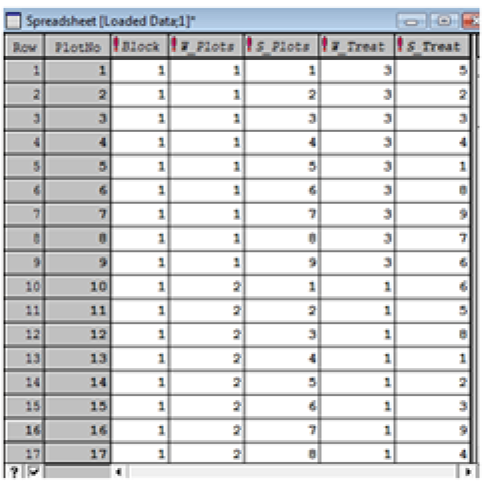
CS16Doc1ab and CS16Doc1cd describe the factors and variables contained in CS16Data1a, CS16Data1b and CS16Data1c and CS16Data1d, respectively. CS16Doc2 describes the contents of C16Data2.

Data management

GenStat can be used to design the experimental layout for Study 1 and produce a corresponding recording sheet by using **Stats → Design → Generate a Standard Design...** and putting appropriate numbers for blocks (or replicates) (namely 3) and whole plot and subplot treatments (namely 4 for dates of planting and 9 for the nine landrace x fertiliser levels.

By clicking the **Options** button on the right hand side and making 'plot labels' sequential numbers a spread sheet similar to that below with 'treatments' randomised to plots can be obtained.





Spreadsheet [Loaded Data;1]*

Row	PlotNo	Block	W_Plots	S_Plots	W_Treat	S_Treat
1	1	1	1	1	3	5
2	2	1	1	2	3	2
3	3	1	1	3	3	3
4	4	1	1	4	3	4
5	5	1	1	5	3	1
6	6	1	1	6	3	8
7	7	1	1	7	3	9
8	8	1	1	8	3	7
9	9	1	1	9	3	6
10	10	1	2	1	1	6
11	11	1	2	2	1	5
12	12	1	2	3	1	8
13	13	1	2	4	1	1
14	14	1	2	5	1	2
15	15	1	2	6	1	3
16	16	1	2	7	1	9
17	17	1	2	8	1	4

Now select the first nine rows (Block 1 W_Plots 1), click **Spread → Sort...** and sort PlotNo into ascending order, ticking the box to 'Place sorted rows at bottom of sheet'. This simply has the effect of moving these rows to the bottom. The nine rows for Block 1, W_Plots 2 are now at the top. Select these but this time sort PlotNo into descending order so that PlotNo is in reverse order 18, 17, 16, 15, 14, 13, 12, 11, 10. These rows again appear at the bottom of the file. Continue throughout the file until PlotNo 1 is back at the top.

The reason for doing this is discussed on the next page.

By right clicking S_Treat and then clicking **Factor → Labels...** we can change S_Treat levels to D0, D1, D2, M0 etc. to describe the factorial nature of the treatments. This modified spreadsheet can now be used for laying out the experiment and for data collection and recording (see alongside). (Note that the actual placement of treatments that was used in the experiment (as shown below) is naturally different from that resulting from the treatment randomisation produced alongside to demonstrate the method.)

Spreadsheet [Loaded Data;1]*

Row	PlotNo	Block	# Plots	S_Plots	# Treat	S_Treat
1	1	1	1	1	3	M1
2	2	1	1	2	3	D1
3	3	1	1	3	3	D2
4	4	1	1	4	3	M0
5	5	1	1	5	3	D0
6	6	1	1	6	3	P1
7	7	1	1	7	3	P2
8	8	1	1	8	3	P0
9	9	1	1	9	3	M2
10	18	1	2	1	1	M2
11	17	1	2	2	1	M1
12	16	1	2	3	1	P1
13	15	1	2	4	1	D0
14	14	1	2	5	1	D1
15	13	1	2	6	1	D2
16	12	1	2	7	1	P2
17	11	1	2	8	1	M0

Planting date									
January	1 P1	2 D1	3 M2	4 P0	5 M1	6 P2	7 D[illegible]	[illegible]	[illegible]
December	18 D2	17 M1	16 D1	15 M0	14 M2	13 P0	1[illegible] P2	[illegible] P1	[illegible] D0
October	19 P1	20 P0	21 M0	22 M2	23 P2	24 D2	25 D0	26 M1	27 D1
November	36 D1	35 P1	34 P2	33 P0	32 D2	31 M0	30 M1	29 M2	28 D0

Exploration and description

So why go through the process described on the previous pages? When a recorder works across the plots he/she will start at plot 1, move along the row, plot by plot, until he/she reaches the end of the row. Rather than walk back to the beginning of the second row he/she can simply turn around and work backwards. So the preparation of the spreadsheet in this way simplifies the task of data collection.

This spreadsheet can now be used for data collection and, with slight further modification, for data analysis. For example, one needs to right click the factor S_Treat and twice apply **Spread → Factor → Recode...** to enter in additional columns factors for Landrace and Fertiliser. Note that there is absolutely no need to sort the file to put treatments into ascending order. GenStat can handle data presented in any order; this was not appreciated when analysis was commenced for this study and, as can be seen, CS16Data1a has been sorted into treatment order. As will be seen under Exploration and Description it then becomes a little difficult to check individual data values against their plot numbers.

Rainfall and temperature data were obtained from Weather South Africa for the duration of the experiments. These are summarised here. Such data are important to collect as they can help in interpreting the experimental results.

Site		Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Ukulinga	Rainfall(mm)	883.4	171.2	159.0	58.2	178.2	78.6	77.4	86.2	0	17.0	0	4.0
	Temperature (°C)	19.6	18.6	19.6	21.9	23.7	24.3	22.7	19.3	18.8	15.3	15.4	18.0
Umbumbulu	Rainfall(mm)	1334.1	139.5	301.2	57.3	133.8	78.7	196.2	122.1	28.4	171.2	3.5	1.8
	Temperature (°C)	20.8	20.4	21.4	22.8	24.3	25.0	23.8	20.7	20.0	17.3	17.0	18.3

For the purpose of this case study only Study 1 at Ukulinga will be used to demonstrate methods of analysis. Two variables, dry corm weight per plant and number of corms per plant, are chosen for further analysis. We shall start with dry corm weight.

Dry corm weight

During field work it was noted that growth was particularly poor for the 4th planting date with zero growth in some plots. Using Stats → Summary Statistics → Summarized Contents of Variates ... it can be seen that half the observations for the 4th planting date have been recorded as missing

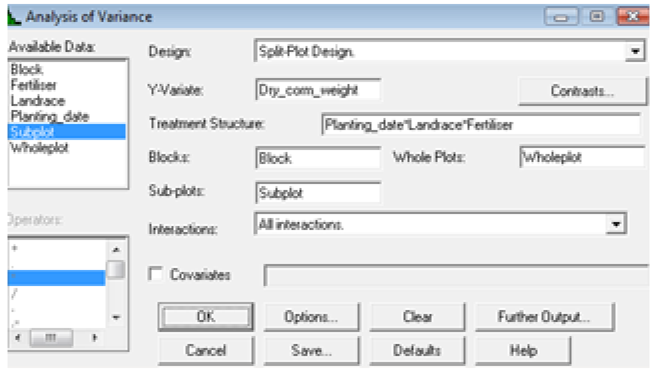
.

```
Summary statistics for Dry_corm_weight: Planting_date 1

     Number of observations = 27
   Number of missing values = 0
                       Mean = 95
                   Variance = 1914

 Summary statistics for Dry_corm_weight: Planting_date 2

     Number of observations = 27
   Number of missing values = 0
                       Mean = 77.7
                   Variance = 867.9

 Summary statistics for Dry_corm_weight: Planting_date 3

     Number of observations = 25
   Number of missing values = 2
                       Mean = 23.5
                   Variance = 199.5

 Summary statistics for Dry_corm_weight: Planting_date 4

     Number of observations = 13
   Number of missing values = 14
                       Mean = 13.22
```

Should these observations have been recorded as missing or zero?

A missing value represents a value that could not be recorded. For several of the variables, such as the mineral determinations, there was no plant material available for analysis. These observations are clearly missing. However, when a variable reflects a zero response (e.g. dry corm weight or number of corms) such data, on reflection, would have been more meaningfully recorded as zero.

Growth was also poor for the 3rd planting date and so one might decide just to analyse the data for the first two plantings. However, for the purposes of this case study, we shall just omit the 4th planting date with its many zeros. This can be achieved by **Spread → Restrict/Filter → To groups (factor levels) ...** and selecting levels 1-3 for Planting_date.



Before proceeding with the statistical analysis of the data we should just check for any extreme data values. By carrying out a preliminary analysis of variance (**Stats → Analysis of Variance ...**) and selecting 'Split-plot Design' (see alongside) we find the message below contained within the output. These residual values are over four times their standard errors and hence outliers.

```
* MESSAGE: the following units have large residuals.

Block 2  Wholeplot 7   Subplot 60   -80.7  s.e. 18.9
Block 3  Wholeplot 12  Subplot 108  109.3  s.e. 18.9
```

The entries on the recording sheets matched the values entered into the spreadsheet and no explanation could be given for these unusual values. They were therefore replaced by the * missing value code and a copy of this sheet saved in a separate spreadsheet 'Edited data' in CS16Data1a.

Let us look at the summarised statistics again (**Stats → Summary Statistics → Summarized Contents of Variates ...**) with these two extreme values removed.

```
Summary statistics for Dry_corm_weight: Planting_date 1

      Number of observations = 25
    Number of missing values = 2
                        Mean = 89.0
                    Variance = 663.8

 Summary statistics for Dry_corm_weight: Planting_date 2

      Number of observations = 27
    Number of missing values = 0
                        Mean = 77.7
                    Variance = 867.9

  Summary statistics for Dry_corm_weight: Planting_date 3

      Number of observations = 25
    Number of missing values = 2
                        Mean = 23.5
                    Variance = 199.5
```

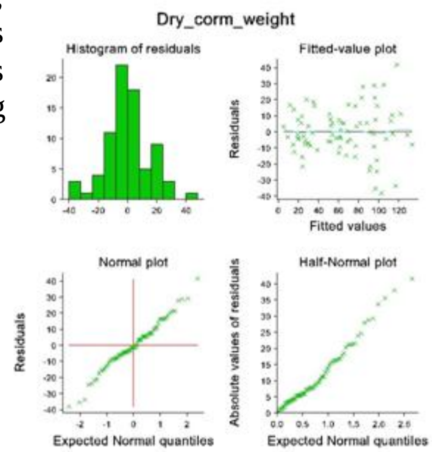
With the large difference in variation among observations when comparing planting dates 1 and 2 with planting date 3 one might consider a transformation to logarithms. Such a transformation depends on means of observations being approximately proportional to the variances of the observations. Dividing the means in the above table by their corresponding variances we obtain ratios of 7.5, 11 and 8.5 for planting dates 1, 2 and 3, respectively. This suggests that a logarithmic transformation could be appropriate. Applying a transformation can complicate the presentation of results. Since analysis of variance is a robust technique we shall first see what happens if we proceed without transforming dry corm weight.

We need to check other analysis of variance assumptions.

By rerunning the analysis of variance and then clicking **Options** on the GenStat screen and then **Residual Plots...** we obtain the graphs alongside.

We can see that the distribution is a little scattered, though essentially normal and that the residual values tend to increase with increasing size of observation. This reflects the differences in variation between planting dates 1 and 2 and planting date 3 observed earlier.

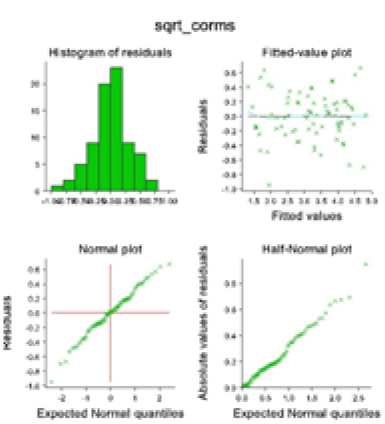
However, the normal plots are reasonably linear at 45^o, and so we shall show the results of analysis of variance based on the raw data.



Numbers of corms

Applying similar methods of analysis to measurements of numbers of corms per plot we find that the number recorded for subplot 55 is four times its standard error. Three other observations are also listed but their deviations are smaller. Again no reason could be found for this anomaly and so this measurement was replaced by an * in the 'Edited data' spreadsheet in CS16Data1a.

Running the analysis of variance again and producing the residual plots we see that the histogram shows signs of skewness to the right and that the normal plots are slightly curved and deviate from the 45^0 line. Measurements of counts, such as in this case, number of corms tend to follow a Poisson distribution. A square root transformation is likely to produce a distribution closer to normality.



Calculating the variable sqrt_corms (**Spread → Calculate → Column...** and rerunning the analysis of variance we can see that the transformed data fit better the assumption of normality.

For number of corms we shall therefore analyse the transformed values.

Statistical modelling

Dry corm weight

We are now ready to carry out analyses of variance (**Stats → Analysis of Variance ...**). By clicking Options and adding a tick for %CV we find at the end of the output that the coefficient of variation for dry corm weight is 30.4%. This is rather large and possibly influenced by the conditions under which the experiment was conducted. Normally one would expect a value closer to 15% for a field experiment.

The output includes the analysis of variance which shows that there are no overall differences among landraces, nor does level of fertiliser have any effect on dry corm weight. However, date of planting has not only a highly significant effect overall but more importantly also a highly significant interaction with Landrace.

```
***** Analysis of variance *****

Variate: Dry_corm_weight

Source of variation    d.f.(m.v.)   s.s.     m.s.   v.r.  F pr.
Block stratum               2      2519.9   1259.9   1.04

Block.Wholeplot stratum
Planting_date               2     72095.9  36048.0  29.72  0.004
Residual                    4      4851.6   1212.9   3.21
Block.Wholeplot.Subplot stratum
Landrace                    2      1115.9    557.9   1.48  0.240
Fertiliser                  2       298.6    149.3   0.39  0.676
Planting_date.Landrace      4     16744.1   4186.0  11.07  <.001
Planting_date.Fertiliser 4          774.1    193.5   0.51  0.727
Landrace.Fertiliser         4      1129.4    282.3   0.75  0.565
Planting_date.Landrace.Fertiliser
                            8      1833.2    229.2   0.61  0.768
Residual                  44(4)   16636.8    378.1

Total                     76(4)  105014.0
```

From the section of the table of means shown alongside it can be seen that the highest yields for Landrace 2 (Mgingqeni) and 3 (Pitshi) occurred when planted in October. In contrast, Landrace 1 (Dumbe-Dumbe) performed better when planting was delayed until November (Planting date 2). Its yield then was similar to that of Pitshi planted in October.

```
***** Tables of means *****
Planting_date          1      2      3      4
                    91.5   77.7   22.5

Landrace               1      2      3
                    69.1   60.6   62.0
Planting_date Landrace      1      2      3
            1            78.8   89.4  106.4
            2           108.8   60.5   63.8
            3            19.6   31.9   15.8
```

We can compare these mean values using standard errors of differences to form a t-test. As the

95% value of t is approximately 2 we can multiply the s.e.d.s by 2 to get a close idea of the statistical significance of individual differences. Thus, 2 x 9.17 = 18.34 gives a measure of the least significant difference (L.S.D) that needs to occur between two landrace means planted on the same date for them to be significantly different (P<0.05).

```
*** Standard errors of differences of means ***

                  Planting_date    Planting_date
                                     Landrace
rep.                    27               9
s.e.d.                9.48           12.08
d.f.                     4           10.18
Except when comparing means with the same
level(s) of
Planting_date                         9.17
d.f.                                    44
```

When planted in October the yield for Pitshi is 27.6 and 17.0 g higher than the yields for the other two landraces. We can thus say that the yield for Pitshi. when planted in October, is significantly higher than that for Dumbe-Dumbe (P<0.05) but not for Mgingqeni. By using the 99% t-value we can similarly calculate the L.S.D. at the P<0.01 level of significance.

Note that the s.e.d and d.f. for comparing means within the table at different levels of planting date are different from those used for the same planting date. The d.f. value of 10.18 is calculated by a formula that takes into account the two residual degrees of freedom (namely 4 and 44) form the different strata in the analysis of variance.

Numbers of corms

From the analysis of variance we see that planting date is again highly significant. There is also a highly significant variation among landraces and, for this variable only a slight indication of an interaction with planting date. As for dry corm weight there was no effect of level of fertiliser on number of corms produced.

```
***** Analysis of variance *****

Variate: sqrt_corms

Source of variation   d.f.(m.v.)    s.s.      m.s.    v.r.  F pr.

Block stratum              2       0.3660   0.1830   0.85

Block.Wholeplot stratum
Planting_date              2      54.1241  27.0621 125.98  <.001
Residual                   4       0.8593   0.2148   1.24

Block.Wholeplot.Subplot stratum
Landrace                   2      11.9741   5.9871  34.67  <.001
Fertiliser                 2       0.1443   0.0721   0.42  0.661
Planting_date.Landrace     4       1.7579   0.4395   2.55  0.052
Planting_date.Fertiliser 4         1.2116   0.3029   1.75  0.155
Landrace.Fertiliser        4       0.6447   0.1612   0.93  0.453
Planting_date.Landrace.Fertiliser
                           8       2.2905   0.2863   1.66  0.135
Residual                  45(3)    7.7707   0.1727

Total                     77(3)   76.2737
```

From the table of means we observe that the numbers of corms per plot deceases from square root means of 3.961 to 2.045 from planting dates 1 to 3. Landraces Pitshi and Mgingqeni produced more corms than Dumbe-Dumbe.

```
***** Tables of means *****
Planting_date    1        2        3        4
             3.961    3.506    2.045
Landrace         1        2        3
             2.637    3.527    3.347

Planting_date Landrace    1        2        3
       1              3.262    4.241    4.379
       2              2.926    3.921    3.672
       3              1.723    2.420    1.991
```

Comparing landrace means for each planting date we see that Pitshi performed as well as Mgingqeni in October but became less productive when planted later.

```
*** Standard errors of differences of means ***
  Planting_date   Landrace   Planting_date
                                      Landrace
rep.      27          27          9
s.e.d.   0.1261      0.1131      0.2037
d.f.      4           45         22.12
Except when comparing means with the same
level(s) of
Planting_date                    0.1959
d.f.                             45
```

Multiplying standard errors of differences by 2 we can calculate approximate 95% L.S.Ds, namely 0.252 among planting date means, 0.226 among landrace means and 0.392 among landrace means at the same planting date. Applying these L.S.D.s to the table of means it can be seen that numbers of corms significantly decreased from planting date 1 to 2 to 3 and that Dumbe-Dumbe (Landrace 1) produced significantly fewer corms than Mgingqeni and Pitshi when planted in October and November. However, in December only Mgingqeni produced a significantly higher number of corms.

By calculating t-values:

(t = [|mean1 - mean2|/s.e (mean1 - mean2)])

Comparison	t-value	d.f.	P-value
Planting date 1 versus 2	3.61	4	<0.05
Landrace 2 versus 1	7.88	45	<0.001
Landrace 3 versus 1	6.28	45	<0.001
Landrace 3 versus 2 (planting date 2)	1.27	45	non-sig
Landrace 3 versus 2 (planting date 3)	2.19	45	<0.05

we can calculate exact significance levels for pairs of comparisons as illustrated in the table. Finally, the coefficient of variation is 13.1%; this is a satisfactory value.

Reporting

Dry corm weight

Having completed the analysis we now need to see how to present the data. There are two ways, either with a table or with a graph. Here we illustrate how a table should be prepared. The table shows mean dry corm weight by landrace and planting date.

Table 1: Comparison of dry corm weights of three taro landraces planted on three dates of planting at Ukilinga Farm.

	Landrace		
Planting date	Dumbe-Dumbe	Mgenggeni	Pitshi
October	78.8	89.4	106.4
November	108.8	60.5	63.8
December	19.6	31.9	15.8
Mean	69.1	60.6	62.0

S.E.D. = 9.2 for comparisons on same date of planting;
= 12.1 across different dates of planting.

Because of the significant interaction between landrace and planting date it is necessary to present the results as a 2-way table. Notice that two S.E.D values are shown in the footnote.

Multiplying each of these values by 2 gives approximate L.S.D.s to apply to differences between pairs of means. For example, the approximate L.S.D. for comparing means on the same line is 2 x 9.2 =18.4.

Some authors feel they need to include superscripts to indicate statistical significance between means. This (as discussed in the Reporting Teaching Guide) is unnecessary for a table as simple as this. The differences in mean values are pretty clear. One also needs to remember that there are differences in variation between planting dates 1 & 2 and 3, as shown earlier, so that the S.E.D. quoted in the table is an average and therefore needs to be interpreted with a degree of caution.

Therefore, the S.E.D. value of 0.11 as shown can be used for any comparison within the body of the table.

The following table shows results for corm numbers. Since the statistical analysis has been carried out on the square roots of corm numbers an extra value is included in parentheses. This is the square of the mean square root value. One could alternatively calculate 95% confidence limits for each mean on the square root scale and then present squared limits to give indications of the likely ranges on the original scale. Statistical comparisons, however, need to be applied to the square roots. Note that on this occasion (since whole-plot and sub-plot mean squares were similar - see earlier analysis of variance table) calculated values for the two S.E.D.s for comparisons within the table are the same to two decimal places. Therefore, the S.E.D. value of 0.11 as shown can be used for any comparison within the body of the table.

Table 2: Comparison of square roots of numbers of corms of three taro landraces planted on three dates of planting at Ukilinga Farm.

	Landrace		
Planting date	Dumbe-Dumbe	Mgengqeni	Pitshi
October	3.26* (10.6)	4.24 (18.0)	4.36 (19.0)
November	2.93 (8.6)	3.92 (15.4)	3.67 (13.5)
December	1.72 (3.0)	2.42 (5.9)	1.99 (4.0)
Mean	2.64 (7.0)	3.53 (12.5)	3.35 (11.2)

S.E.D. = 0.20 for comparisons within body of table;
= 0.11 for comparisons between landrace means averaged over planting dates.
* square roots of number of corms; squared values in parentheses

Findings, implications and lessons learned

General conclusions from the Ukulinga field trial are:

- All landraces can be planted in October without additional fertiliser.
- Planting in December or January is too late to achieve good yields.
- Of the three landraces Dumbe-Dumbe is the best since it produces a smaller number of corms with a similar dry corm weight to the other two. This means that it produces larger corms which are easier to handle compared to the other landraces.

From a research strategy perspective the case study demonstrates the importance of setting out a plan at the beginning of a project. However, there are lessons to be learned.

- Plans do not necessarily have to be set in stone. If an early study in the research process can be analysed promptly this can guide the design of a subsequent study. This may be difficult to achieve under the constraints of a PhD programme (such as in this case study) but it is likely, as illustrated by question 8 under Study questions, that Study 2 could have been simplified if data analysis of Study 1 had been done more quickly.
- Efficient and timely data management and analysis is important. Formal statistical analysis can wait until later in the research process but simple descriptive methods used early on can often provide an adequate summary of an experiment that helps to lead the way forward and revise, where appropriate, earlier plans.
- Researchers must not forget the importance of setting out procedures for data collection and computer entry as part of the research strategy, and ensuring that there is adequate

time a for this component of the work to be done in a timely way.

In terms of data collection the case study has demonstrated

- how GenStat can be used to lay out the design of an experiment, randomise treatments to plots and prepare the recording sheet,
- how plot numbers were rearranged in alternate rows to allow the recorder to traverse the field experiment more easily.

From a statistical design and analysis point of view the case study has described the use and analysis of a factorial split-plot design and shown how different standard errors are calculated to compare means at different strata levels.

Split-plot designs have their place when it is difficult or impossible to apply all treatments at the same plot level. Thus, in this example, it would have been impracticable to plant landraces on different dates to individual plots within different rows.

Nevertheless, it is important to note that, with the larger whole plot size, whole-plot treatments will usually be estimated with a higher variance than sub-plot treatments. This needs to be taken into account in the experimental design.

Study questions

1. Use `CS16Data1b` and follow the methods used in this case study to analyse dry corm weight and number of corms at the field site Umbumbulu. Compare your results with those of Ukulinga and interpret any differences that you find.
2. Discuss the advantages and disadvantages of a split-plot design compared with that of a randomised block. You can use the examples in this case study to support your arguments. Discuss the possibilities of arranging the samples in Study 2 as a randomised block rather than a split-plot within each of the rooms.
3. Carry out analyses of variance for variables Ca, Mg and K in `CS16Data1a`. Based on the results for these minerals what can you say about the nutritional benefits of each of the three landraces? This is one of the requirements set out in the Research strategy. Similarly analyse specific gravity. High specific gravity is one of the qualities needed for crisp making. What do the results tell you?
4. We have seen that yields are reduced when planting is later than November and that this affects not only the mean yield but also the experimental error. An alternative would be to analyse data for the first two planting dates only. Do this for dry corm yield and number of corms and compare with the analysis based on the three planting dates. Which method would you recommend for dealing with these data?
5. In reporting the results of this case study it is decided to present the mean results for dry

corm weight and number of corms in the forms of bar charts rather than tables. Display the mean values shown in the tables under Reporting in bar charts. Would it be better to list landrace means within planting date or vice versa?

6. Carry out a split-split-plot analysis of variance on the data for specific gravity contained in CS16Data2. Compare the structure of the analysis of variance with that shown under Study design to ensure that you have filled in the GenStat dialog box correctly. Examine each of the strata residual mean squares. What does this tell you about the variation within the rooms?
7. Study 2 uses only one cold room and store room. What is the disadvantage of this? Replicating the experiment in time might go some way to accounting for possible environmental room to room variations. Prepare a suitable plan for doing so.
8. Study 2 required a lot of work. Suppose it had been possible to analyse the results of Study 1 at Ukulinga and Umbumbulu (see questions 1 and 2) before embarking on Study 2. What differences would you make to the design of Study 2 having concluded that Dumbe-Dumbe was the recommended landrace?
9. Rewrite the section describing the design for Study 2 under Study design based on your proposal in question 8 for redesigning the experiment
10. Prepare an outline of the analysis of variance that you might use to analyse data contained in files CS16Data1c and CS16Data1d. Month can be considered as a repeated measure, so reference to Case Study 15 may help.

Related reading

Mare, R.M. 2006. Phytotron and field performance of taro [*Colocasia esculenta* (L.) Schott] landraces from Umbumbulu. MSc. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Modi, A.T. 2007. Effect of indigenous storage method on performance of taro [*Colocasia esculenta* (L.) Schott] under field conditions in a warm subtropical area. *South African Journal of Plant and Soil* **24**: 214-219. Abstract

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