Department of Agriculture Fisheries & Forestry - Australia

Land & Water Resources Research & Development Corporation

CVAP Climate Variability in Agriculture R&D Program

Australian Grassland and Rangeland Assessment by Spatial Simulation

The Aussie GRASS

High Rainfall Zone Temperate Pastures Sub-project

FINAL REPORT

April 2001

Queensland Government Natural Resources and Mines

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Northern Territory Department of Primary Industry & Fisheries

NSW Agriculture

Primary Industries and Resources SA

South Australia

Land & Water Conservation

Queensland Government Department of Primary Industries

Australian Grassland and Rangeland Assessment by Spatial Simulation

(*Aussie GRASS*)

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QNR9

Final Report

for the

Climate Variability in Agriculture Program

April 2001

Graeme Tupper, John Crichton, Doug Alcock and Harpal Mavi

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1 Sub-project details

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2 Introduction

The Final Report of the 'Development of a National Drought Alert Strategic Information System' project (Brook 1996) made a number of research and extension recommendations should a second round of funding be obtained to continue the work. These recommendations then formed the basis for the Aussie GRASS proposal to the Climate Variability in Agriculture Program (CVAP) of the Land and Water Resources Research and Development Corporation (LWRRDC).

A key component of the Aussie GRASS proposal was the recognition that use of the GRASP pasture production model in the prototype national modelling framework may not be optimal, particularly for those temperate vegetation types in the high rainfall zone of New South Wales (NSW). These concerns were based on a number of climatic and biological aspects that differentiate these vegetation communities from those in drier and/or hotter regions, including rainfall seasonality, plant growth and decay rates, plant community demographics and functionality, dynamic shrub processes, shrub/tree browse component, and plant community composition. Hence the High Rainfall Zone Temperate Pastures sub-project was charged with, amongst other things, refining the national spatial model so as to ensure its applicability to the eastern half of NSW.

3 High Rainfall Zone Temperate Pastures sub-project objectives

The objectives of the High Rainfall Zone Temperate Pastures sub-project were:

1. Run GrassGro at specified locations in all relevant shires in NSW, using up-to-date weather information and information on local soil types and pasture species. The simulations will be based on an indicator herd or flock - say Merino wethers or Angus steers - stocked at a typical rate for the district.

2. Run the simulations forward in time to obtain a probability distribution of the likely state of the production system in 3 weeks, 3 months and 6 months time using the SOI analogues or other appropriate forecast systems that develop.

3. Check the output against PROGRAZE demonstration data, MRC SGS program data, and other grazing trials.

4. Collate species data from researchers and the literature.

5. Develop parameters for additional species from collated data.

6. Map GrassGro output in NSW Agriculture's Geographic Information System (GIS).

7. Compare GrassGro outputs against spatial 'Aussie GRASS' simulations based on GRASP.

4 Achievements

This section will briefly outline how each of the linked objectives has been achieved. Where more detailed data is available, and considered of value to the reader, these will be presented as separate sections within this report.

4.1 Objective 1: GrassGro simulations

Run GrassGro at specified locations in all relevant shires in NSW, using up-to-date weather information and information on local soil types and pasture species. The simulations will be based on an indicator herd or flock - say Merino wethers or Angus steers - stocked at a typical rate for the district.

GrassGro (Moore *et al.* 1997) was run routinely at 65 localities, typical of high rainfall NSW, using published soil information where available and local weather data provided by the SILO project (Beswick *et al.* 1999). Rural Land Protection Board (RLPB) districts were preferred to shires as they are of more even size. Simulations were based on a flock of Merino wethers stocked at a conservative rate for the district based on the long-term carrying capacity obtained by modelling and the local weather record. This work is detailed in Section 5.

4.2 Objective 2: Run the simulations forward in time to obtain a probability distribution of the likely state of the production system in 3 weeks, 3 months and 6 months time using the SOI analogues or other appropriate forecast systems that develop.

Under specified deteriorating conditions at particular localities, GrassGro was run forward for a three-month period to obtain the likely duration and severity of a feed shortage or other event. Analogue years and other appropriate forecasting systems were evaluated as experimental forecasting tools. However, the choice of forecasting system remains subjective and as a result of simulation experiments undertaken as part of this sub-project, it was decided to use the variance of the local weather record to obtain a temporal probability using percentiles. This information was then interpreted using official forecasts from the Bureau of Meteorology (BoM). A probability distribution map of pasture growth, based on Rural Land Protection Divisions (RLPD) and derived from the simulations was produced regularly for validation by regional officers.

The development of the GrassGro-equivalent temperate parameter sets for the Aussie GRASS model, as detailed in Section 7, means that three-month forecasts of pasture growth for the eastern half of NSW are produced each month as part of the operational spatial model runs. The Aussie GRASS model uses the DPI SOI phase system to select analogue years.

4.3 Objective 3: Check the output against PROGRAZE demonstration data, MRC SGS program data, and other grazing trials.

Due to the nature of the GrassGro model, validation requires long periods of pasture data combined with stock information. There is also a need for detailed soil analysis, including bulk density and moisture holding characteristics. Due to the limitation of available pasture parameter sets, the site from which potential validation data is sourced must be dominated by one or more species for which the model has been parameterised. It is very difficult to find data sets from paddock scale trials where all of these conditions are met.

It was originally hoped that NSW Agriculture's Pasture Animal Assessment Program (PAAP) would provide useful validation data. While pasture type and available data were suitable at some PAAP sites, no information was available regarding soil parameters. Validation has been attempted with data from the Beef CRC project at Glen Innes but experimental design (including long periods without pasture measurements) precluded successful simulation of this complex grazing system.

In development of the GrassGro pasture growth model, many grazing experiments were reviewed by the CSIRO Plant Industry group for potential use in validation of the specific pasture parameter sets. Validation runs have been developed for several sites across southern Australia including several in NSW. The validation process by CSIRO is ongoing and all new iterations of the program are validated against standard data sets to ensure model stability in commercial releases. For this reason it was decided to accept the validation efforts of CSIRO as sufficient evidence of the suitability of the GrassGro model for use in the temperate high rainfall environments and to spend greater effort in development of a method for its use in the Aussie GRASS project.

4.4 Objective 4: Collate species data from researchers and the literature.

It was recognised early in the development of the Aussie GRASS project that the existing set of parameterised species for GrassGro was restrictive and limited the geographical extent over which GrassGro might be used, particularly in hot/dry seasonal environments.

Under the Aussie GRASS project, the task of developing a wider set of parameterised species for GrassGro was contracted to CSIRO. Emphasis was placed on developing ecotypes for certain native grasses. The results of the CSIRO parameterisation work are described in Section 6.

4.5 Objective 5: Develop parameters for additional species from collated data.

See Objective 4.

4.6 Objective 6: Map GrassGro output in NSW Agriculture's Geographic Information Systems (GIS).

The output from GrassGro simulations described in Section 5 was mapped on an RLPD basis using GIS software. An example is shown in Figure 1.

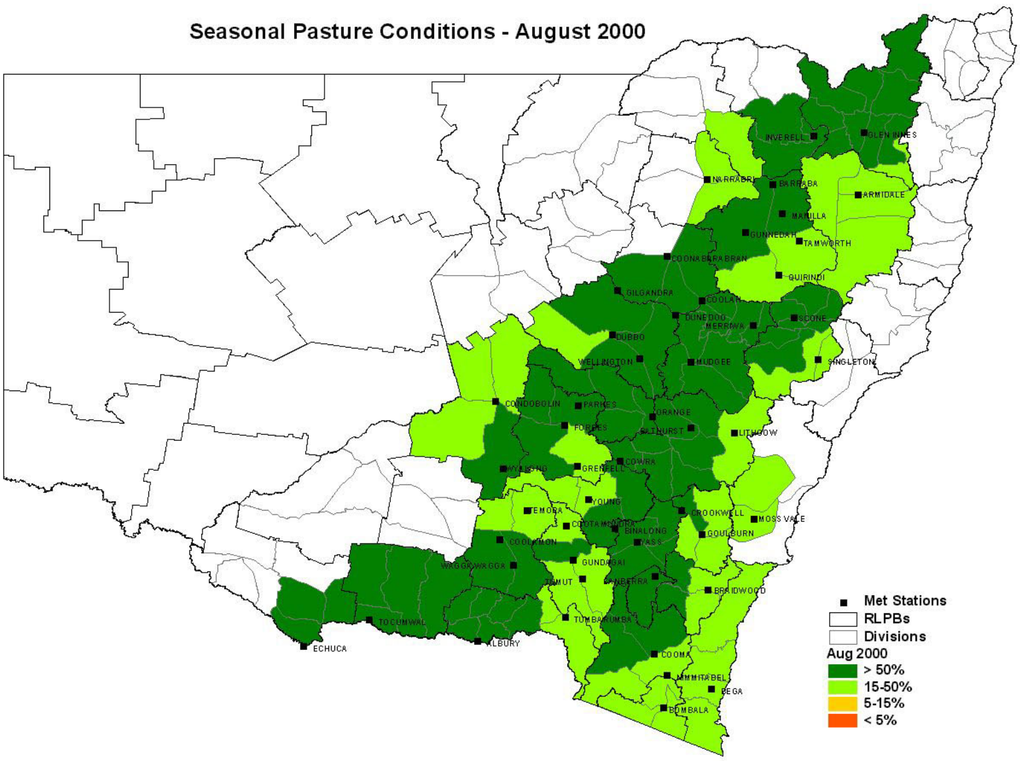


Figure 1. Relative seasonal pasture condition classes as at August 2000 as simulated by the GrassGro model.

NSW Agriculture regional staff were involved in Aussie GRASS via a co-operative pilot project which was initiated in December 1999. District staff reviewed products and contributed to the accuracy and timeliness of GrassGro output. Their feedback was invaluable in developing the Relative Livestock Performance graphs based on Metabolisable Energy Intakes, which were used to illustrate seasonal pasture conditions (Figure 2).

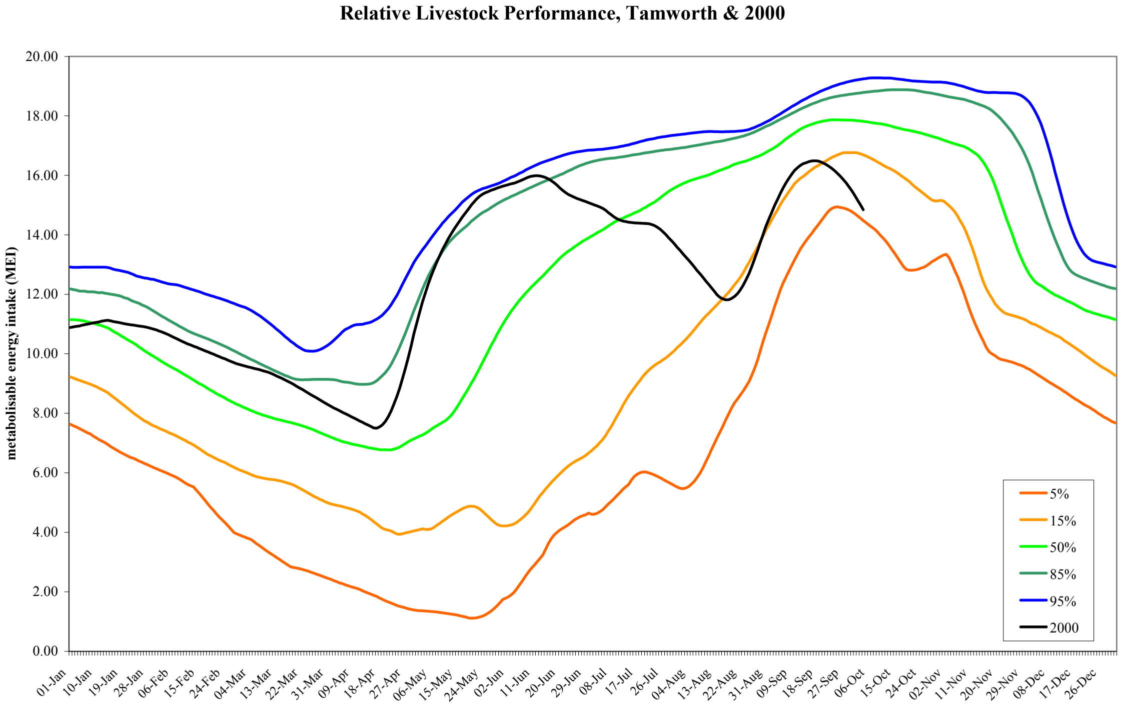


Figure 2. Relative Livestock Performance graph for Tamworth as at the end of September 2000.

4.7 Objective 7: Compare GrassGro outputs against spatial 'Aussie GRASS' simulations based on GRASP.

This objective was refined to better represent the aims of the Aussie GRASS project as:

> *GrassGro, or whatever model is selected for this zone, is to be fully integrated within the Aussie GRASS spatial modelling framework*

This change was endorsed by the Steering Committee on 17-9-1997. To achieve this new objective, it was necessary to produce a set of GRASP model parameters, which were as equivalent to the GrassGro species parameters as possible (allowing for fundamental differences between the models) and to use each of these parameter sets in the same areas of NSW within the spatial model as were being modelled to achieve Objective 6. The major advantages of this approach were that it enabled: 1) delivery of a 'uniform' product for all NSW using the spatial Aussie GRASS model; and 2) the modelled output for the eastern half of NSW to reflect the spatial variation in climatic factors as represented in the climate surfaces, compared with running the GrassGro model for a number of spatially independent 'indicator' stations. This work is detailed later in Section 7.

5 Use of the GrassGro model in the High Rainfall Zone Temperate Pastures sub-project

5.1 Introduction

The GrassGro model was developed by the CSIRO Division of Plant Industry over a number of years and represents many man-years of research by various agencies throughout the temperate pasture zones of Australia. GrassGro was selected as the preferred model for this sub-project and was used to produce output representing seasonal conditions for a variety of locations throughout eastern NSW. This output was then interpreted relative to historical data, and incorporated in a GIS to provide a spatial viewpoint.

5.2 Background

5.2.1 The GrassGro model and spatial representation

The GrassGro model uses daily weather data and soil properties for a locality to model the growth of the specified pasture and the animals grazing it. The model is described in detail in Moore *et al.* (1997).

'Patched' weather data (Beswick *et al.* 1999) for over 75 stations throughout the High Rainfall Zone, for the period from 1957 to the present, were obtained from the SILO Patch Point Database. Only 65 stations were modelled regularly as ten stations gave unsatisfactory model outputs as their climates were too harsh for the available GrassGro species parameter sets. Soil data from published sources were preferred for the modelling.

GrassGro is a point model and runs on a personal computer. The computing resources available to NSW Agriculture were inadequate to model a fine grid of points and tie them together into a pseudo spatial net similar to the Aussie GRASS model. Instead, GrassGro was run at specified localities using soil and weather data for the locality, and the districts were compiled into a map using GIS software. The mapping units were the administrative areas of the RLPB districts (and their divisions). Figure 3 shows the areas of eastern NSW that were modelled using GrassGro and the species parameter set used in each RLPD. In future, when significantly more weather localities are available, it may be possible to use Local Government Areas as mapping units. This would allow comparisons and accuracy assessments against ABS agricultural statistics.

The seasonal pasture condition of each district is the current pasture condition relative to long-term seasonal pasture performance percentiles. The seasonal map for a particular month shows the relative condition of each division at the end of the month (Figure 1). Seasonal condition is expressed in categories. The classes defined are outlined in Table 1. Areas of class 1 (the best class), for example, have seasonal pasture growth better than the long-term median and are shown in dark green. Warm colours are used to show those areas where seasonal conditions are moderate or poor.

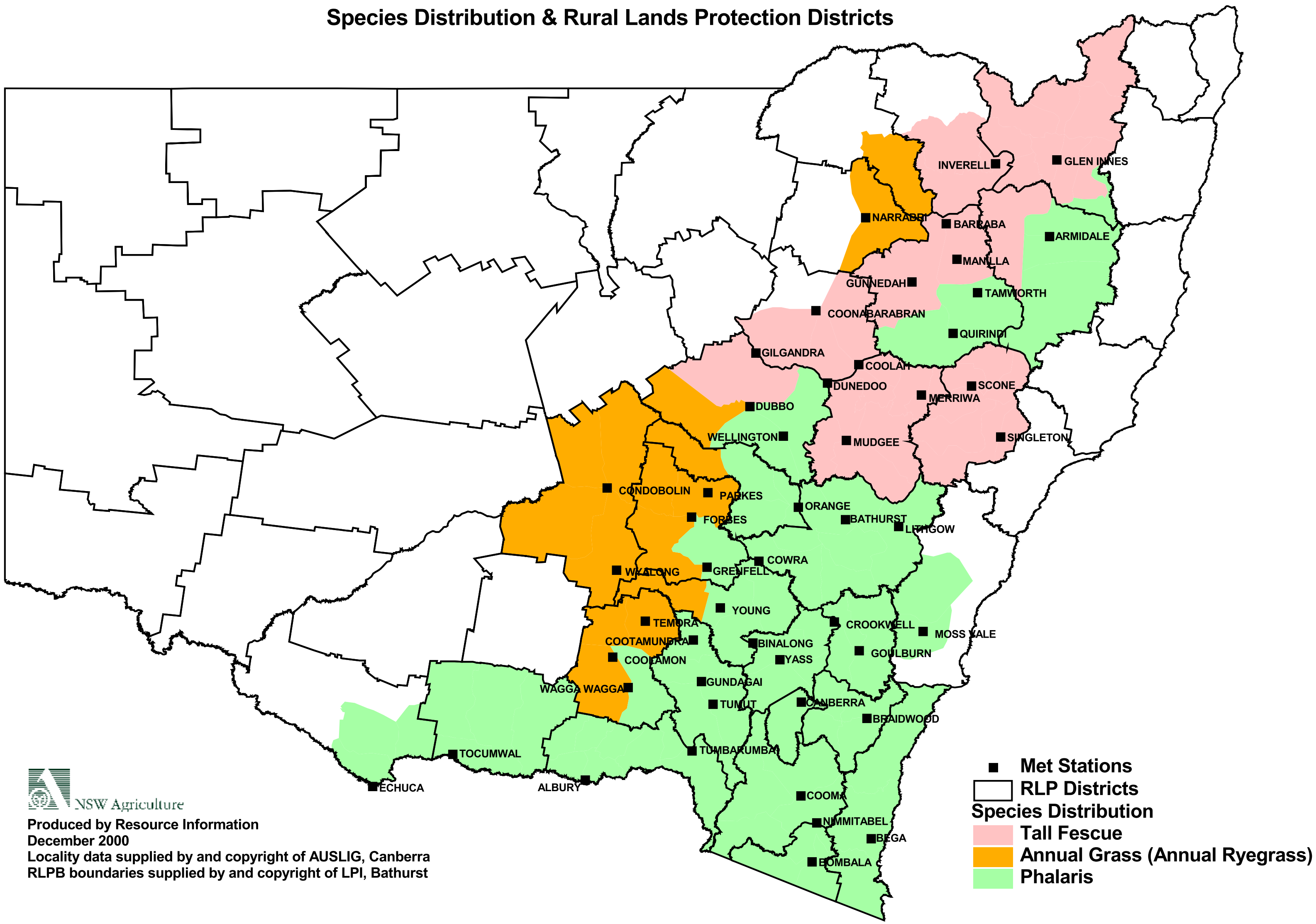


Figure 3. The NSW High Rainfall Zone modelled with GrassGro and the species used in the model.

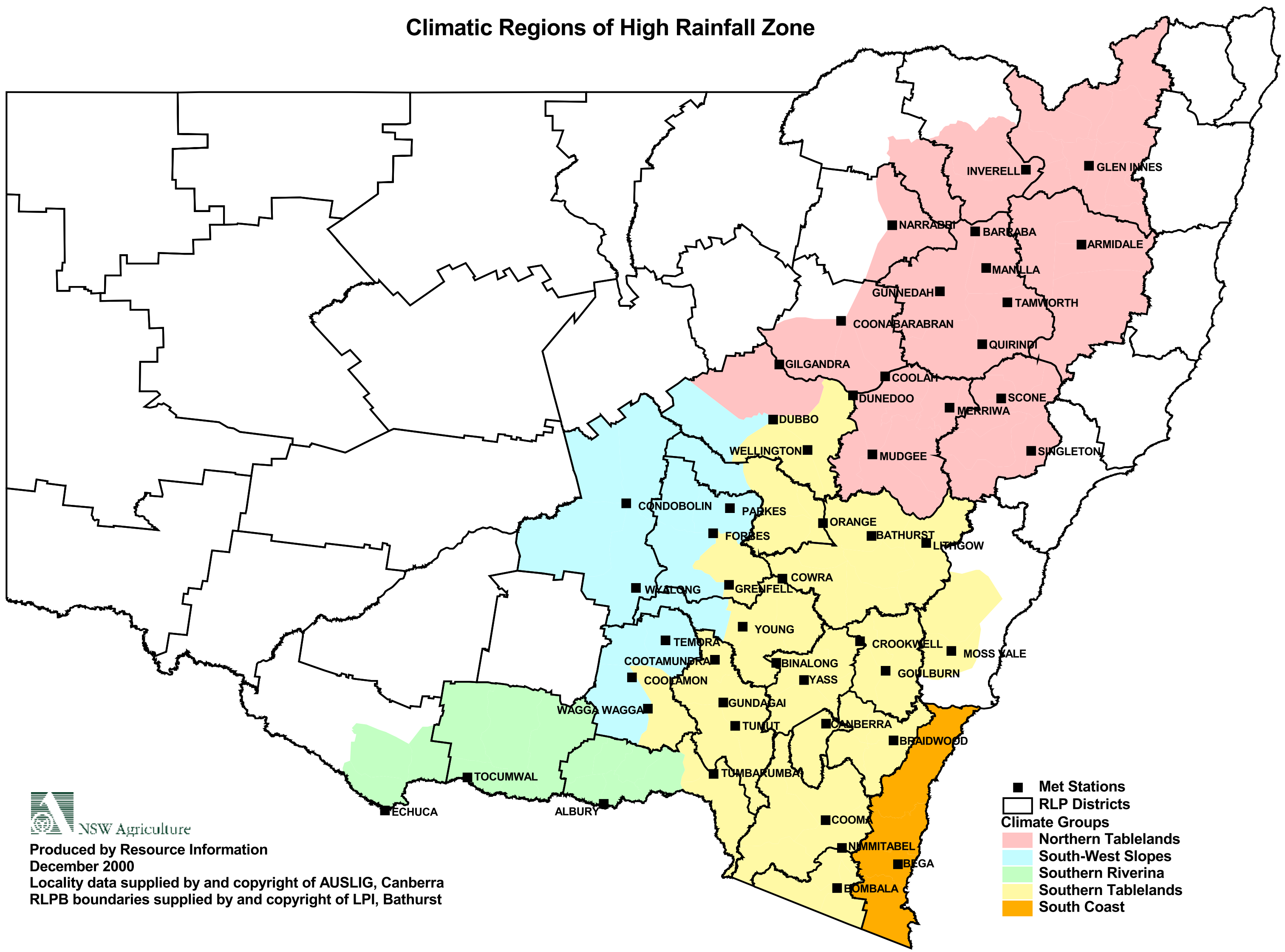


Figure 4. Climatic regions of NSW modelled using GrassGro.

Table 1. Seasonal pasture condition class related to percentiles of long-term pasture condition.

Class No.	Percentile	Colour Code
Class 1	>50	dark green
Class 2	15-15	light green
Class 3	5-15	orange
Class 4	<5	red

At the beginning of this sub-project, some 24 introduced grasses, legumes, fodder crops and fodder weeds had already been parameterised for GrassGro. Preliminary parameter sets for other species were still under development. As a result of the limited range of parameter sets, CSIRO was contracted by the Aussie GRASS project to expand the range of parameterised ecotypes for GrassGro. Unfortunately progress was not as rapid as was hoped, mostly due to the absence of any published data about the new ecotypes, and the introduction of new species was delayed. During the life of the project, white clover and two lucerne cultivars became available and several native grasses were still under development at the time of writing. Such grasses may become valuable as companion species to fill a possible seasonal feed vacuum at certain places. In particular, *Bothriochloa* was promising as a complementary species for modelling in north eastern NSW and *Danthonia* will be important in more western areas.

In GrassGro, component species of the pasture sward are modelled individually. The production of the sward is the sum of the contributions and interaction of the individual members of the sward. Initially, experiments were carried out using a model sward of several complementary species (e.g. a grass and a legume) in an attempt to better characterise areas. However, as a result of running the GrassGro model continuously over decades, relative seasonal comparisons sometimes became less reliable as unexpected changes in pasture composition occurred over long runs.

This may be due to exaggerated competition for water and light that lead to dramatic fluctuations in sward composition and in some cases, species extinctions. For simplicity, and to avoid these problems, it was decided to simulate the growth of a single suitable species (an indicator species) at each location. A grass, representative in production and phenology of a typical sward at the location was chosen for modelling the district. This stratagem does not allow for the small contribution of species with a different seasonal growth pattern, e.g. summer growth in the Southern Tablelands. Since out of season growth does not make a large or persistent contribution to herbage mass this was seen to be an acceptable compromise.

5.2.2 Regions modelled

Initially, modelling was concentrated in three broad areas of eastern NSW, where the bulk of pasture production is concentrated: the Southern Tablelands; the South-West Slopes; and the Northern Tablelands (Figure 4). Two other areas, the Southern Riverina and the South Coast were added later. These five areas are characterised by different climatic patterns at a coarse scale and were an important determinant of the GrassGro species selected for each RLPB division. Outside these temperate high rainfall areas, modelling was limited by the lack of suitable parameterised pasture species for GrassGro.

The Southern Tablelands, westward from the Blue Mountains, is typical of the temperate grazing country on which much of the State's wool and meat are grown. The elevated areas are largely long-term pastures characterised by autumn, winter and spring growth. Phalaris, an improved perennial on which the modelling here was based, is a common component of the pasture and is phenologically similar to the other major contributors to pasture biomass in this area. In summer, when phalaris is dormant, perennial grasses such as *Microlaena* can make a significant contribution in some areas but the bulk of growth takes place in the cooler months.

In the Northern Tablelands, rainfall becomes more seasonal. Summer rain and higher temperatures combine to make fescue a suitable species for modelling north of the Bathurst/Orange RLPB districts. Unlike phalaris, which is summer dormant, this fescue ecotype grows all year round given suitable conditions. Fescue was used in all the northern areas in the early runs. Following feedback from district officers, however, phalaris was substituted particularly in elevated areas, notably the Tamworth and Armidale districts, where most growth occurs in the non-summer period.

The South-West Slopes lie west of the Southern Tablelands as far as the 500 mm isohyet and are devoted largely to cropping. As a result of crop research, particularly good published soil data is available for pasture modelling purposes, for example, Geeves *et al.* (1995). In southern and eastern parts, extending north of Wagga, phalaris remains a suitable indicator species for pasture modelling. In the pasture leys of the west and north, annuals are more representative than phalaris, and annual ryegrass was used as the indicator species.

The Southern Riverina was modelled using phalaris. Rainfall is on the low side at 450 mm but it is evenly distributed throughout the year.

The North Western Slopes and Plains have a subtropical climate and GrassGro is no longer considered an appropriate model to use. It was not feasible to model production in the North and Central Coasts due to the lack of validated parameter sets for C4 grasses, typical of these areas. GRASP (with existing parameter sets) may provide better pasture simulations of the hot, dry and coastal areas mentioned.

It may be possible to better model the South Coast with GrassGro when Kikuyu parameters are more fully tested. For this project, phalaris was used.

5.3 GrassGro simulations

5.3.1 Soil data

A major obstacle to processing more localities in the time available was the paucity of quality soil data at almost all sites. A growth model needs good estimates of plant available water, which may be estimated from soil moisture parameters, including conductivity and bulk density. Unfortunately little published information includes soil moisture parameters, and what was available usually referred to a crushed and sieved sample, not to an undisturbed soil core. An otherwise good published source of soil information was marred by missing values (Geeves *et al*. 1995). This reduced the number of soils for which adequate data were available by half. Older sources commonly had incomplete soil descriptions. An otherwise well-documented set of long-term pasture trials conducted by NSW Agriculture contained no soil data. A dozen suitable soil data sets for the Southern Tablelands and Slopes were found, and fewer elsewhere.

Where no better information existed, this fact was noted and 'artificial' soil water conditions were estimated from texture using GrassGro defaults. The textures and depths of horizons were obtained from survey data or from the Atlas of Australian Soils.

5.3.2 Livestock and stocking rate

The indicator livestock used in the model were to have been wethers or steers according to the characteristic grazing enterprise of the district. Attempts to model a replacement strategy and age structure of steers to impose a relatively constant stocking rate on the pasture throughout the year were unsuccessful. Consequently, small merino wethers were modelled in all areas. This substitution is of no consequence as the animals are used to integrate the quantity and quality of available pasture to a common index. To reduce all areas to a common level and eliminate the effects of under or over stocking, the stocking rate for each locality was determined based on achieving approximately 35% utilisation of long-term pasture growth. A 35% utilisation rate is reasonably representative of the rates achieved by graziers in many areas

5.3.3 Model runs, weather updates and output

Model runs were started on the 1st January 1957. Initial conditions for standing dry matter, litter and underground biomass were set at median values for the locality. In areas where the sward was annual ryegrass, an adequate seed pool was established. Soil moisture was set half way between wilting point and field capacity. Dry feed was distributed equally among the available digestibility pools.

The simulations were run in batches at monthly intervals. When weather updates were received from SILO, a few days into each new month, records for the 65 weather stations were updated to the first day of the month. Updates were rolling two-year revisions that included data for the current month and adjustments to earlier records, the result of quality control by BoM and SILO. Previous records held within the update period were overwritten by the updated data and lost.

Once the weather records were updated, the GrassGro simulation files were opened one by one and the end date adjusted, the initial conditions saved, and the simulation re-run from the start (1957). Each simulation generated a 10 Mb binary file from which data was extracted into tables or graphs. For Aussie GRASS, two tables were extracted for each simulation: 1) daily herbage metabolisable energy intake (MEI) percentiles from 1957 to the present; and 2) daily MEI intakes from 1997 to the present. The two tables were imported into a spreadsheet, which was used to smooth the values and plot a Relative Livestock Performance graph for each locality (see Section 5.3.4; Figure 2). The spreadsheet also calculated the pasture class used for the seasonal conditions map.

The process of running simulations, extracting tables and drawing graphs was done manually. Attempts to increase throughput by writing a sufficiently general spreadsheet macro to automate graph production were unsuccessful.

5.3.3.1 GrassGro model version

In April 2000, a pre-release copy of a new version of GrassGro was obtained from CSIRO and was used in all subsequent modelling. This version differed incrementally from the earlier version in a number of aspects: the water balance, pasture, animal and soil subroutines had all been improved. It also ran more quickly. Perhaps the most obvious change was in the reduced effect of waterlogging on restriction of animal feed intake.

5.3.4 Pasture performance index

The GrassGro model is capable of producing a range of soil, pasture and animal outputs. A measure of pasture growth and availability was needed to compare pasture status in different areas. The available mass of green herbage could be used in spring and available dead herbage and litter could be used in summer, but the other seasons were problematical. The quality and quantity of available feed vary throughout the year in response to growing conditions, grazing and management. A single measure or index of the quality and quantity of available pasture was required that could be used all year round. Rather than using any of the direct measures of pasture, it was decided to use livestock performance to integrate the relative quantity and quality of pasture on offer at any point in time. The measure used for this was the Metabolisable Energy Intake (MEI) of the simulated livestock, which is proportional to herbage mass and digestibility within certain limits.

The Relative Livestock Performance was calculated as the MEI (14-day running mean) of the stock present in real time and was plotted relative to five MEI percentiles (5, 15, 50, 85 and 95) calculated over the period from January 1957 to the present. The seasonal conditions map (Figure 1), produced as a summary of pasture condition over the high rainfall zone, was based on the current state as at the end of the month. The 1998 MEI curve was also generally included in each graph as early 1998 was part of the most recent El Niño event, when conditions for several districts were below the 5th percentile (Figure 5). This was considered important initially to enable our collaborators to interpret the graph in dry conditions.

Using a relative index rather than an absolute measure allowed a more meaningful extrapolation across the landscape since the sward was represented by a single species. The relative index also compensated for the different pasture qualities and management strategies within a district.

5.3.5 Seasonal forecasting

While dry conditions prevail, the natural response is to wonder how long they will last and how long before pastures recover and green feed is again available. Various forecast options were examined to address this issue including the use of analogue years.

It was considered that 3-months was an appropriate forecast lead-time, one month was too short and 6-months was too long. For a period longer than 3-months, the possible outcomes multiplied and a poor forecast was the result. It was concluded that the analogue procedure was subjective, both in the choice of the forecasting system used to select the analogue year, (whether SOI, SST or a combination of the two) and in the identification of the specific analogue year from a number of possible analogues. Had the SOI phase been used, for example, a different analogue year would have been suggested as nearly every month went by.

An alternative approach, which was finally adopted, was to use the climatic record to generate probabilities for a range of possible scenarios. Taking the official 3-month forecast, and using it in conjunction with the long-term climate record for the stations concerned, was the preferred stratagem. GrassGro was used to analyse a three-month segment of every year since the beginning of the climate record and percentiles were appended to the year line. Before such a forecast was undertaken, as a precondition, it was specified that the current MEI needed to lie between the fifth and fifteenth percentile and maintain a downward trend.

5.4 Results

5.4.1 MEI - an indicator of seasonal variability

MEI was initially an unfamiliar measure to use as an indicator of seasonal conditions. On the graphs (e.g. Figure 5), the ordinate increased from zero to 20 MJ/head/day. Below about 8 MJ/d wethers lose weight. As conditions worsen, at some point depending on their initial condition score and available pasture, the model will feed supplement to maintain a (low) condition score. Supplement had little effect on the graphs as only nutrition from herbage intake is taken into account. At higher MEI values, the lines were flatter and the percentiles closer together as the stock, with a surfeit of feed available, cannot eat beyond their capacity.

In good years, the constant stocking rate based on 35% utilisation of long-term pasture growth resulted in fat animals and potential intakes not being reached. This has the effect of narrowing the distribution above the 80^{th} percentile in the best seasons. In poor years, with sub-optimal pasture availability, the MEI curves closely mirrored pasture condition. For the purposes of Aussie GRASS, dry conditions and shortages of feed were of more interest than times of plenty because of the need to prevent losses and overgrazing of pastures.

Seasonal variability is a fact of life: farmers, graziers and pastoralists are familiar with the losses that can accompany a late break or a dry spring. The MEI graphs show seasonal variability well. Serious situations take time to develop, and the graphs illustrate their progress. When the year curve drops below the 15^{th} percentile, it serves as a warning to focus interest on the district and add it to a short list for possible action if the line continues on a downward trend. For farmers it signifies the need to investigate and review all options including feed availability, and decide on an action date. When the line drops below the 5^{th} percentile, equivalent to a 1 in 20-year event, conditions are critical and urgent action is required.

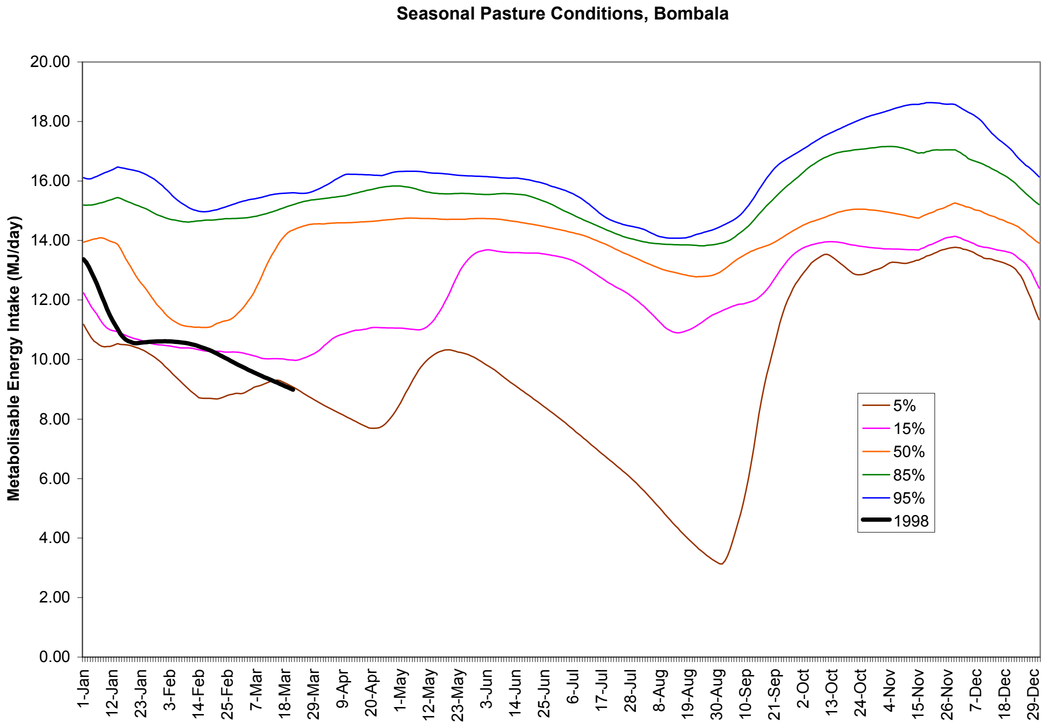


Figure 5. Relative Livestock Performance graph for Bombala as at March 1998.

All of the broad climatic areas modelled (Figure 4) showed a spring or early-summer maximum in availability and reliability of feed. Feed is reliable when the MEI percentile lines on the graph are close together. Data for the southern areas, like Canberra and Bombala (Figures 5 and 6), showed that, on average, reliable feed is available year-round (>7.5 MJ/head/day) in six years out of seven (the 15th percentile) years. At Bombala, in the seventh year, a cold, dry winter can lead to a severe feed shortage until mid-September.

Glen Innes (Figure 7) and Armidale (Figure 8) have good feed availability for nine months in all but the worst years. In 50% of years at Glen Innes there will be a feed deficit, which may occur between June and October. In one year in twenty this is likely to extend longer than three months.

Tamworth (Figure 9) and Wagga (Figure 10) have MEI graphs of similar shape, which show a feed shortage beginning in mid-December, which in the worst years, continues until June, the least reliable time of year. Tamworth illustrates the need for a summer-growing grass to grow in concert with phalaris, since ‘off-peak’ summer growth contributes far more in the summer-dominant rainfall environments.

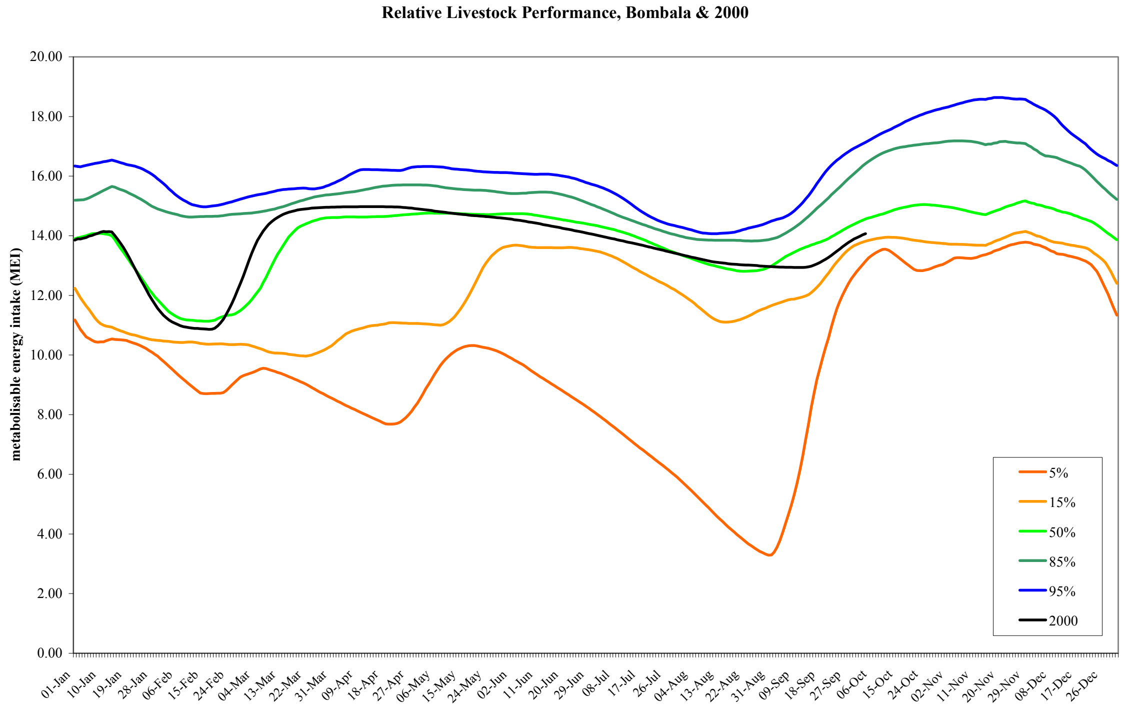


Figure 6. Relative Livestock Performance graph for Bombala as at the end of September 2000.

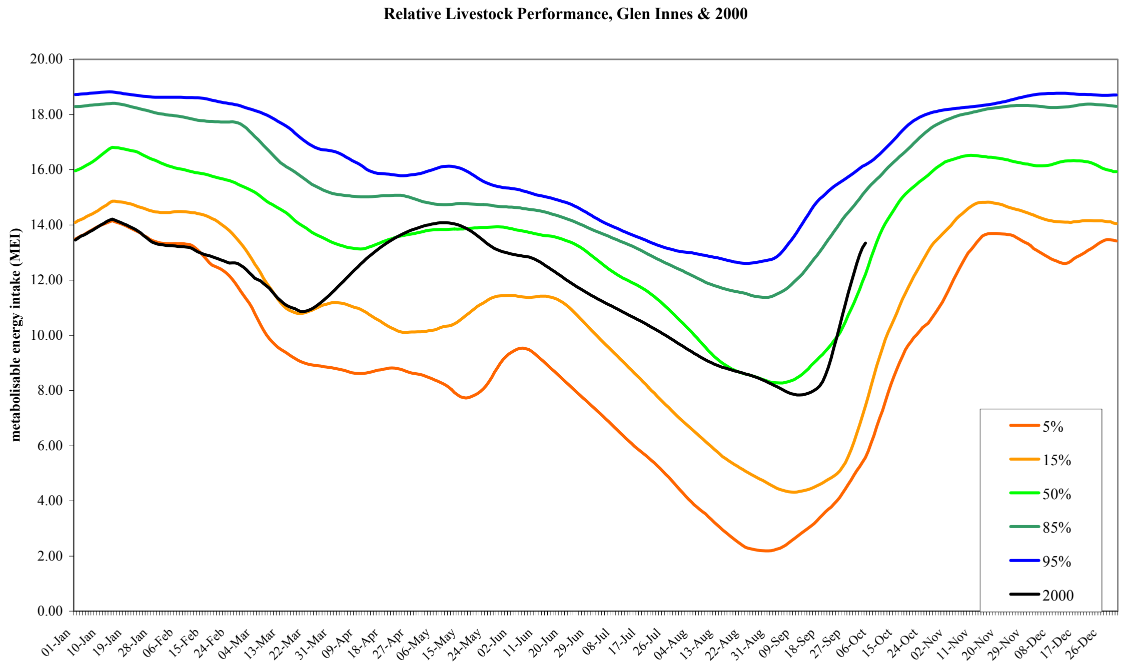


Figure 7. Relative Livestock Performance graph for Glen Innes as at the end of September 2000.

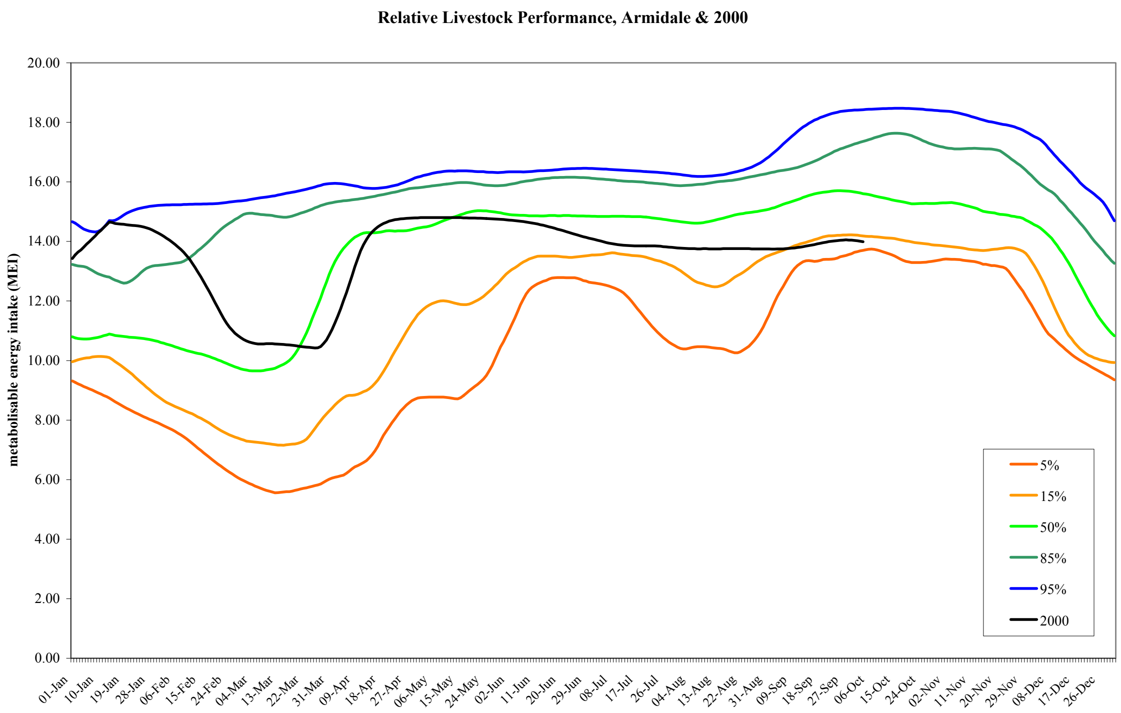


Figure 8. Relative Livestock Performance graph for Armidale as at the end of September 2000

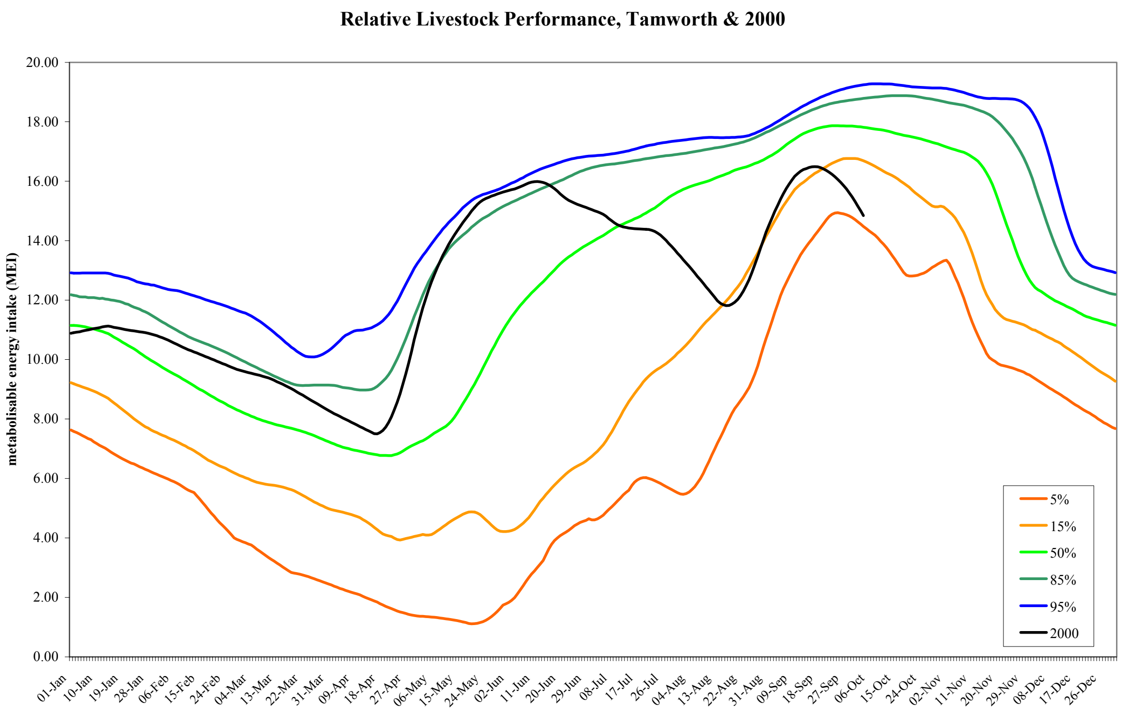


Figure 9. Relative Livestock Performance graph for Tamworth as at the end of September 2000.

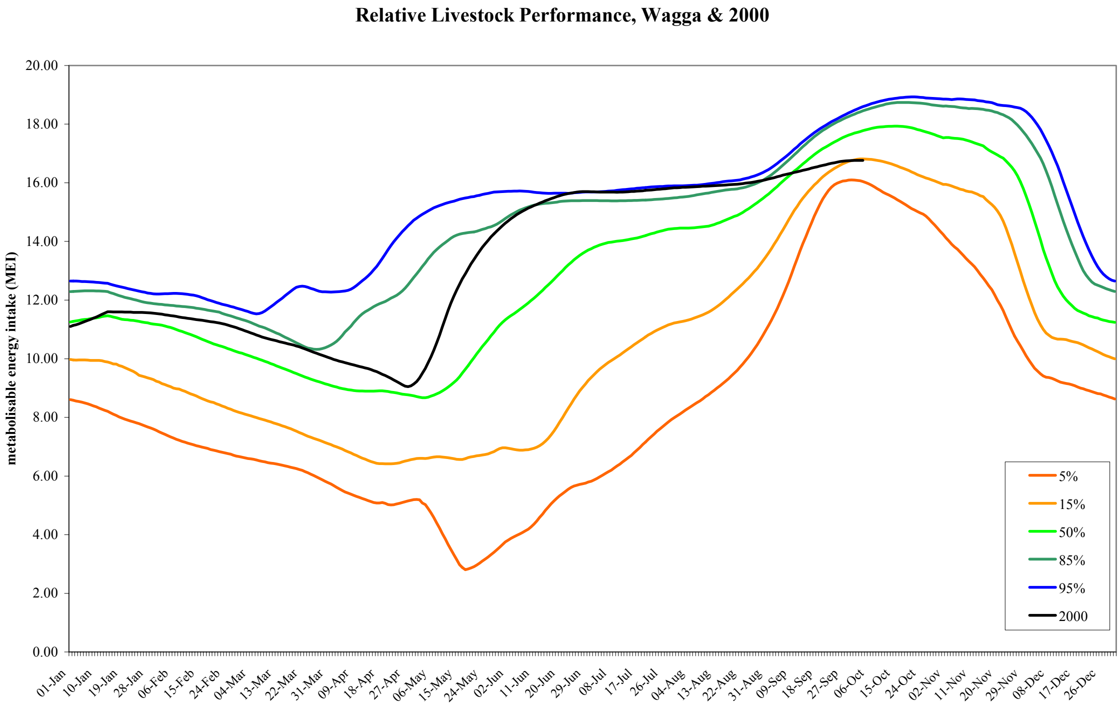


Figure 10. Relative Livestock Performance graph for Wagga as at the end of September 2000.

5.4.2 Seasonal forecasting

The approach adopted in this sub-project for assessing probable future seasonal conditions is shown for Bombala in Figure 11. By mid-March 1998, conditions were close to a one in twenty-year dry event and still in decline. How long before median pasture levels might again be achieved? Figure 11 shows the 1998-year line at Bombala, in March 1998, extended by 3 months by appending percentiles ranging from the 5th to the 95th. Looking at the 95th percentile shows that recovery to median levels of pasture availability could not be expected before mid-May (60 days) by even the most optimistic grazier. Supplementary feed would be required for much of that time. Taking a pessimistic view, illustrated by the 15th percentile, suggested a much longer period of feed shortage.

The BoM 3-month forecast for the period stated, 'the autumn rainfall over most parts of NSW is likely to exceed the median amounts'. On that basis, by following the 50th percentile line, it would take less than approximately three months (90 days) for feed to recover. This is valuable information for planning purposes. Estimates could be made, feed sources investigated and feed ordered before the severity of the dry period became apparent to most people. Figure 12 shows that median pasture availability was finally reached in early-July (112 days), nearly four months after the forecast was made.

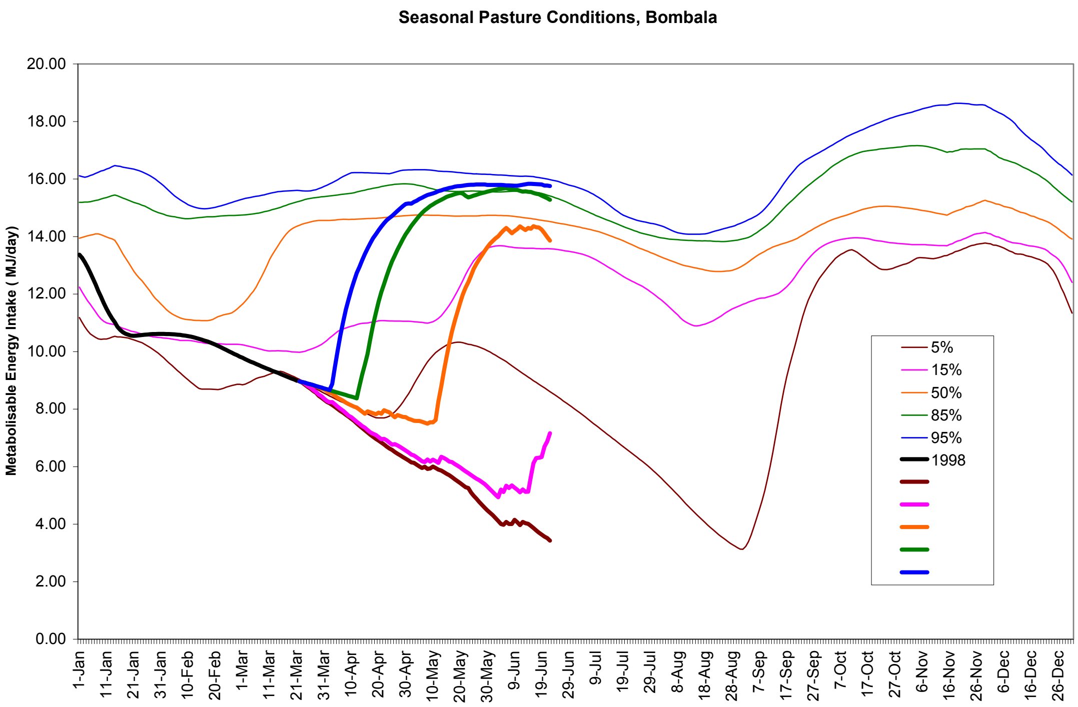


Figure 11. Relative seasonal conditions for Bombala as at March 1998 with a three month forecast using the 5th, 15th, 50th, 85th, and 95th percentiles.

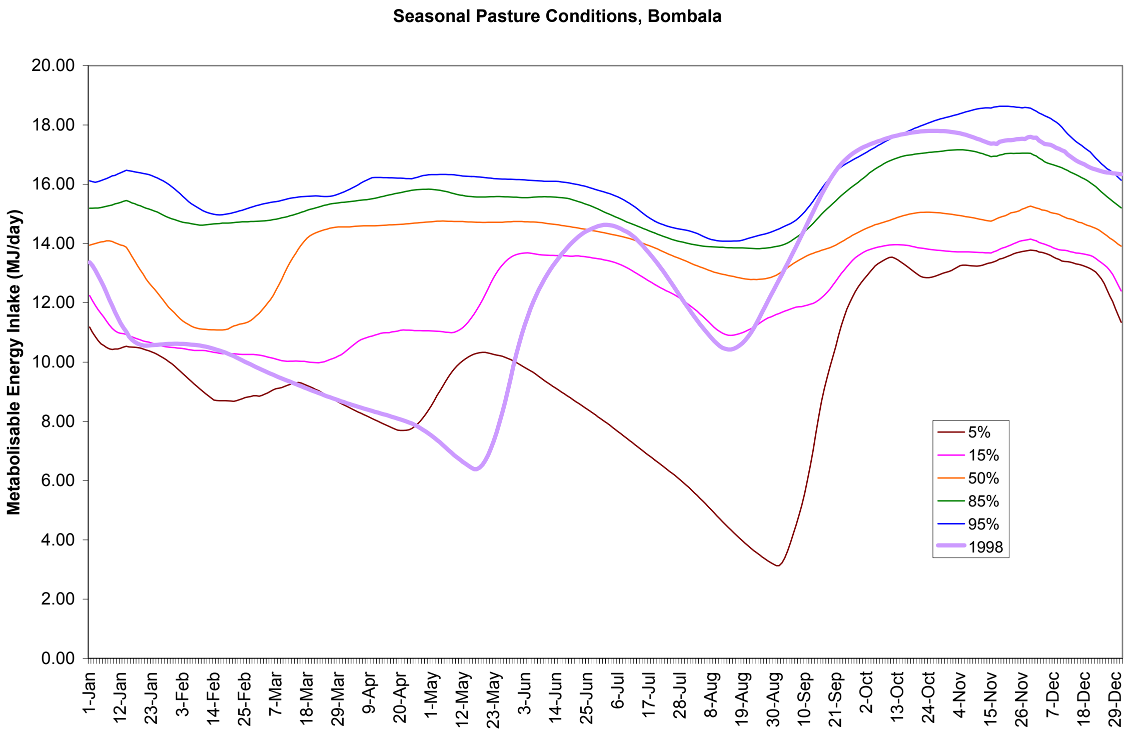


Figure 12. Relative seasonal conditions for Bombala for 1998.

5.4.3 Pilot project

In December 1999, a pilot project was begun to promote and encourage feedback on this work from NSW Agriculture extension staff in the districts. Early each month, MEI graphs were prepared for 13 locations in the southern part of the State, and four in the north. The graphs were distributed to experienced agronomists and livestock officers who were familiar with their districts. A set of graphs was also sent to the Department's Climatology Unit at Tamworth.

Feedback was sought from the district officers on current accuracy, on past accuracy as illustrated by previous year lines, and on ways to improve the presentation. Initially, extension officers needed experience with the concepts and format used. This took time to develop and during this period useful feedback was obtained on the size, direction and significance of the shifts that took place in the graphs as the seasons unfolded.

Feedback was valuable in bringing to light occasional errors in the BoM rainfall database when the graph told a different story to the officer's recollection. Early feedback from district staff concentrated on the unfamiliarity of the MEI units and the difficulty many found in translating them into familiar terms. Experience with the graphs led to better understanding by district staff. Confusion occurred when paddocks were bare of green feed but the graphs showed only moderately poor conditions, implying that less-palatable feed was still available in the paddock. Other criticism, related to graphical congestion, were overcome by using more-distinct colours.

In summer, in warmer areas where phalaris was modelled and the grass was dormant, the graphs showed declining levels of feed, largely carried over from early summer. This was also a source of confusion. Paddocks at that time appeared to be full of native grasses, which were perceived as providing a valuable supplementary source of feed while phalaris was dormant. It is easy to overestimate summer production. Evaporation is high and summer storms are frequently short and intense, so that runoff is high. Little water may be available for growth even if plants are vegetative. Future modelling of native grasses by CSIRO will evaluate their contribution to feed budgets in mixed swards.

5.5 Conclusions

The Relative Livestock Performance graphs have proved useful as indicators of week-by-week seasonal conditions. However, considerable training is required before most users are comfortable with these graphs. The inability of the pre-release GrassGro version to simulate multiple species at the same time was a limitation in some areas at some times, but will hopefully be overcome in the near future. Similarly, the release of GrassGro parameter sets for native grasses is essential.

6 New GrassGro species parameter sets

A consultancy was let to CSIRO to broaden the range of parameterised ecotypes for GrassGro and thus increase the applicability of the model for the purposes of the Aussie GRASS project. White clover and two lucerne varieties have been released. Several native grasses still under development should be valuable as contributors to counteract the feed vacuum at certain times of year. In particular, *Bothriochloa* promises to be a complementary species for modelling in northern NSW and *Danthonia* will be important in western areas. GrassGro parameter values for additional species are shown in Appendix 1.

7 Parameterising GRASP for the high rainfall zone - high fertility temperate pastures for Aussie GRASS[1]

7.1 Introduction

The pasture growth model GrassGro was selected by the sub-project team as being the most appropriate model for use in the high rainfall zone of NSW. After some preliminary discussion, it was judged that it was not economically feasible to explore further the potential to incorporate the GrassGro code into the existing Aussie GRASS spatial modelling framework. Hence the capability of using the existing Aussie GRASS spatial model (Carter *et al.* 2000), which is itself based on the GRASP model (Littleboy and McKeon 1997), to simulate temperate pastures in the high rainfall zone of NSW was investigated and the findings are reported here. As a result, Dr J. Crichton (NSW Department of Agriculture) carried out simulations with GrassGro for 44 locations in the high rainfall zone of NSW and these simulations provided the 'data' for developing GRASP parameter sets. However, because of continuing developments with GrassGro these simulations are not regarded as definitive but as example output still in the process of evaluation.

7.2 GRASP: a brief history

GRASP is a daily time-step soil moisture/plant growth model simulating the hydrological processes of runoff, through-drainage, tree and grass transpiration and soil evaporation (Rickert and McKeon 1982); and the biological processes of plant growth, senescence, detachment, decomposition, trampling, animal intake and animal (sheep and cattle) growth (McKeon *et al.* 1982). These general hydrological and biological processes are common to most models used to simulate plant production from historical daily climate records (McKeon and Scattini 1980, Rickert *et al.* 2000). However, as detailed later, there are several 'specific' hydrological and biological processes which are not common to the two models, GrassGro and GRASP.

GRASP was developed as a general purpose forage production model with parameterisations for wheat in Western Australia (WA) and Queensland, forage crops such as lablab, oats and maize in south-east Queensland, sown and native perennial tropical pastures (McKeon *et al.* 1986). Since 1987, development and application have concentrated on perennial native pastures in northern Australia (McKeon *et al.* 1990, Day *et al.* 1997, Carter *et al.* 2000) with subsequent extension to temperate rangelands (McKeon *et al.* 1996). A major feature of GRASP was that it was designed as an empirical model that could be easily parameterised from common pasture field measurements (McKeon *et al.* 1990, Day *et al.* 1997) and remote sensing data (Carter *et al.* 2000).

[1] This section has been authored by G.M. McKeon, J. Yee Yet and W.B. Hall, Queensland Department of Natural Resources and Mines.

7.3 Aussie GRASS: use of GRASP

Aussie GRASS initially used the model GRASP with parameterisations for native perennial pastures in northern Australia (Carter *et al*. 1996). In Queensland, these parameters were derived from extensive ground monitoring (Hassett *et al.* 2001), remote sensing (Carter *et al.* 2000) and exclosures (Day *et al.* 1997). Southern temperate pastures were simulated by changing temperature response parameters and using other parameters derived for C_3 pastures in Queensland (J.O. Carter personal communication).

In the LWRRDC project National Drought Alert and Information Systems (QPI20, Brook *et al.* 1996), GRASP was successfully parameterised for native temperate rangeland communities (in Gascoyne, WA; Alice Springs region, Northern Territory; Kinchega, Western NSW) simulating a reasonable proportion of seasonal variability in pasture standing dry matter (SDM; McKeon *et al.* 1996). Subsequently Day (1999) independently validated the Kinchega parameterisation for a rangeland community in north-western Victoria (Zallar 1986). GRASP had also been successfully parameterised for cleared native temperate pastures near Canberra (Williams *et al*. 1999). Williams *et al.* (1999) also measured pasture growth under trees and found no effect on pasture growth. Since GRASP only includes the competitive effects of trees (water and nitrogen, Scanlan and McKeon 1993) the measured effect could not be simulated and is the subject of a new project.

Given the partially successful experience of parameterising GRASP for temperate rangelands it was decided to investigate its use in the high rainfall - high fertility zone. GrassGro has been parameterised and tested for high rainfall - high fertility temperate pastures, and hence simulation output from GrassGro was regarded as suitable to parameterise GRASP. The advantage of this approach was that a much greater quantity of data (e.g. daily output for 43 years) was available for parameterisation than is able to be collected in field trials. However, a disadvantage of this approach is that any processes represented in GrassGro that are not modelled in GRASP (e.g. effect of water logging on plant growth) would not be accurately simulated by GRASP. The following review examines the differences between GrassGro and GRASP to develop a strategy for adapting GRASP. We have used the publication of Moore *et al.* (1997) as our reference document. The parameters used in GrassGro for phalaris, fescue and annual ryegrass are given in Tables 2a, b and provided a basis for estimating GRASP parameters.

Table 2a. Parameter values used in simulations of soil moisture and pasture growth by GrassGro. Simulations and values provided by Dr J. Crichton (NSW Department of Agriculture). (N.B. Table continues over the following 2 pages)

Parameter	Units	Parameter description	Tall Fescue	Phalaris	Annual ryegrass
Annual			FALSE	FALSE	TRUE
Grass			TRUE	TRUE	TRUE
Legume			FALSE	FALSE	FALSE
Long Day			TRUE	TRUE	TRUE
Develop					
K(V,1)	/d	rate of vernalisation at 0ºC	0.05	0.05	0.43
K(V,2)	/ºC	curvature of vernalisation rate with temperature	0.1	0.1	0.29
K(V,3)	ºC	base temperature for degree-day calculations	5	5	4.7
K(V,4)	hr	day length to initiate reproductive growth	11	11	
K(V,5)	ºd	degree-days to initiate reproductive growth			340
K(V,6)	ºd	degree-days to start of flowering	?	?	990
K(V,7)	d	maximum length of flowering period			30
K(V,8)	0-1	effect of water stress on flowering duration			0.5
K(V,9)	ºd	degree-days before reproduction can end	1800	800	1300
K(V,10)	0-1	soil moisture threshold for end of reproduction	0.05	0.05	0.05
K(V,11)	ºC	temperature threshold to break summer dormancy		17	
K(V,12)	0-1	soil moisture threshold to break summer dormancy		0.6	
K(V,13)	d	initial days of cool moist conditions for end of summer dormancy		9	
K(V,14)	d	days for summer dormancy requirement to reduce to zero		160	
K(V,15)	0-1	effect of drought on increasing time to flowering	0	0	0
K(V,16)	ºC	lagged temperature threshold to end phenological cycle	-50	-50	-50
K(V,17)	hr	Daylength threshold to end winter-dormancy at 0ºC			
K(V,18)	hr/ºC	Decrease in winter-dormancy daylength threshold with temperature			
K(V,19)	0-1	Decrease in summer-dormancy moisture threshold after K(V,14) days		0.5	
Light					
1/K(I,1)	kg/ha	tissue weight required for LAI of 1	950	900	800
K(I,2)	0-1	relative contribution of stem to assimilation			
20*K(I,3)	kg/ha/d	maximum NPP at 20 MJ/m2 radiation and 12 hr daylength	150	160	170
K(I,4)	J/m2/hr	effect of radiation intensity on radiation use efficiency	0.6	0.6	0.6
K(I,5)	(k)	light extinction coefficient under ungrazed conditions	0.6	0.6	0.6
K(I,6)	(k)	light extinction coefficient under heavily grazed conditions	0.9	0.9	0.7
Growth					
K(T,1)	ºC	lower temperature for 5% of maximum NPP	4	1	3
K(T,2)	ºC	lower temperature for 95% of maximum NPP	12	9	11
K(T,3)	ºC	upper temperature for 95% of maximum NPP	18	18	20
K(T,4)	ºC	upper temperature for 5% of maximum NPP	30	30	26
K(W,1)	0-1	ASW threshold for growth limitation	0.25	0.25	0.3
K(W,2)	0-1	ASW threshold for reduced transpiration	0.35	0.35	0.35
K(W,3)		curvature of waterlogging effect	23	23	23
K(W,4)	0-1	WFPS threshold for waterlogging effect	0.85	0.85	0.85
Alloc'n					
K(A,1)	R:S	target root:shoot ratio during vegetative growth	3	2.5	0.6
K(A,2)	R:S	target root:shoot ratio after flowering	1	1	0.1
K(A,3)	0-1	maximum allocation to reproductive structures			0.5
K(A,4)	0-1	leaf:stem allocation parameter			
K(A,5)	%/d	maximum RGR of shoot in summer-dormant grasses		0.5	
K(A,6)	%/d	maximum RGR of root in summer-dormant grasses		0.2	
K(A,7)	0-1	proportion of stem or shoot at flowering to be relocated			0.1
K(A,8)	ºd	degree-days for end of relocation from stem to repro. structures			450
K(U,1)	0-1	threshold growth limit for remobilization from below ground	0.6	0.6	
K(U,2)	%/d	relative rate of remobilization from below ground	1	1	
Death					
K(D,1,l,lf)	%/d	death rate of live leaf (shoot in grasses)	0.3	0.3	1
K(D,1,l,st)	%/d	death rate of live stem (ignore in grasses)			
K(D,1,s,lf)	%/d	death rate of senescing leaf (shoot in grasses)	5	20	50

Table 2a continued. Parameter values used in simulations of soil moisture and pasture growth by GrassGro. Simulations and values provided by Dr. J. Crichton (NSW Department of Agriculture).

Parameter	Units	Parameter description	Tall Fescue	Phalaris	Annual ryegrass
K(D,1,s,st)	%/d	death rate of senescing stem (ignore in grasses)			
K(D,2)	ºC	temperature for 5% mortality at the first frost	-3	-3	-2
K(D,3)	ºC	temperature for 95% mortality at the first frost	-11	-11	-11
K(D,4)	ºC	frost-hardening factor	1	1	1
K(F,1,lf)	%/d	maximum specific fall rate of leaf (shoot in grasses) from rain	3	3	5
K(F,1,st)	%/d	maximum specific fall rate of stem from rain (ignore in grasses)			
K(F,2,lf)		curvature of fall rate-rain relationship for leaf (shoot)	0.1	0.1	0.1
K(F,2,st)		curvature of fall rate-rain relationship for stem			
K(F,3,lf)	%/dse/d	effect of trampling on fall of dead leaf (shoot in grasses)	0.01	0.01	0.02
K(F,3,st)	%/dse/d	effect of trampling on fall of dead stem (ignore in grasses)			
K(R,1)	%/d	specific root loss rate at 10ºC	0.3	0.3	0.5
K(R,2)	Q10	Q10 for root loss rate	1.5	1.5	1.5
DMD					
K(M,1,l,lf)	DU/d	decline rate of 60% DMD live leaf (shoot) with no water stress	0.15	0.15	0.15
K(M,1,l,st)	DU/d	decline rate of 60% DMD live stem with no water stress			
K(M,1,s,lf)	DU/d	decline rate of 60% DMD senescing leaf (shoot) with no water stress	0.5	0.5	0.5
K(M,1,s,st)	DU/d	decline rate of 60% DMD senescing stem with no water stress			
K(M,2)	Q10	Q10 for digestibility decline of live and senescing material	2	2	2
K(M,3,lf)		effect of ASW on decline rate of live and senescing leaf (shoot)	1	1	1
K(M,3,st)		effect of ASW on decline rate of live and senescing stem			
K(Y,1,lf)	DU/d	decline rate for 60% DMD dead leaf (shoot) under dry conditions	0.05	0.05	0.05
K(Y,1,st)	DU/d	decline rate for 60% DMD dead stem under dry conditions			
K(Y,2,lf)	DU/d	effect of moist conditions on decline rate of 60% DMD dead leaf (s	0.25	0.25	0.25
K(Y,2,st)	DU/d	effect of moist conditions on decline rate of 60% DMD dead stem)			
K(L,1)	DU/d	Max. rate of litter digestibility decline under dry conditions	0.02	0.02	0.02
K(L,2)	DU/d	Max. rate of litter digestibility decline under wet conditions	1	1	1
K(L,3)	ºC	Temperature for 5% of max. rate of litter digestibility decline	0	0	0
K(L,4)	ºC	Temperature for 95% of max. rate of litter digestibility decline	8	8	8
K(Q,80%)		Scalar for digestibility decline of 80% DMD tissue	1.00	1.00	1.00
K(Q,70%)		Scalar for digestibility decline of 70% DMD tissue	1.00	1.00	1.00
K(Q,50%)		Scalar for digestibility decline of 50% DMD tissue	1.00	1.00	1.00
K(Q,40%)		Scalar for digestibility decline of 40% DMD tissue	1.00	1.00	1.00
Seeds					
K(S,1)	%/d	rate of 'hardening' of immature seeds			3
K(S,2)	d	length of period of innate dormancy			90
K(S,3)	%/ºC/d	effect of maximum temperature on seed 'softening'			0.5
K(S,4)	ºC	threshold maximum temperature for seed 'softening'			25
K(S,5,s)	%/d	specific death rate for soft seeds			1
K(S,5,h)	%/d	specific death rate for hard seeds			0.01
K(G,1)	0-1	surface ASW above which germination takes place			0.24
K(G,2)	ºC	minimum temperature for germination			2
K(G,3)	ºC	lower bound of optimal temperature range for germination			32
K(G,4)	ºC	upper bound of optimal temperature range for germination			35
K(G,5)	ºC	maximum temperature for germination			46
K(G,6)	d	time to first seedling emergence under optimal conditions			2.5
K(G,7)	d	time to complete seedling emergence under optimal conditions			5.1
K(G,8)	%	proportion of reproductive structures which is actually seed			40
K(Z,1)	0-1	value of the seedling stress index at which mortalities begin			0.8
K(Z,2)	0-1	value of the seedling stress index for 100% seedling mortality			1
K(Z,3)	d	establishment scalar			2.2
Other					
Root max	mm	parameter for estimating rooting depth	1000	1000	650
SF		'selection factor' (1.7 for improved species)	0	0	0
HF		'height factor' (min. 1.0)	1.3	1.3	1
CP(80%)	%	crude protein content of 80% digestible herbage	25	25	25

Table 2a continued. Parameter values used in simulations of soil moisture and pasture growth by GrassGro. Simulations and values provided by Dr. J. Crichton (NSW Department of Agriculture).

Parameter	Units	Parameter description	Tall Fescue	Phalaris	Annual ryegrass
CP(70%)	%	crude protein content of 70% digestible herbage	18	18	18
CP(60%)	%	crude protein content of 60% digestible herbage	12	12	12
CP(50%)	%	crude protein content of 50% digestible herbage	7	7	7
CP(40%)	%	crude protein content of 40% digestible herbage	3	3	3
dg(80%)	%	protein degradability in 80% digestible herbage	90	90	90
dg(70%)	%	protein degradability in 70% digestible herbage	80	80	80
dg(60%)	%	protein degradability in 60% digestible herbage	70	70	70
dg(50%)	%	protein degradability in 50% digestible herbage	60	60	60
dg(40%)	%	protein degradability in 40% digestible herbage	50	50	50
RQ(s,u)	1-6	equivalent digestibility class for unripe seeds (may be blank)			5
RQ(s,r)	1-6	equivalent digestibility class for ripe seeds (may be blank)			6
DMD(s,u)	%	DM digestibility of unripe diaspores			45
DMD(s,r)	%	DM digestibility of ripe diaspores			45
CP(s)	%	Crude protein content of diaspores			20

7.4 GrassGro and GRASP

7.4.1 Pasture growth

GRASP combined several well-established 'empirical' approaches to modelling plant growth:

1. the 'growth index' approach (Fitzpatrick and Nix 1970, Smith and Stephens 1976, Williams and Gardener 1984, Mott *et al*. 1985) in which growth is calculated as a potential growth rate multiplied by a growth index which is a function of soil moisture, temperature and radiation indices;
2. 'water use' approach (Rose *et al.* 1972, McCown *et al.* 1974, Van Keulen 1975, White 1978, Tanner and Sinclair 1983, McKeon *et al.* 1982, 1990, Hammer *et al.* 1987) in which growth is calculated from some combination of transpiration and vapour pressure deficit; and
3. 'radiation use efficiency' approach in which growth is calculated from intercepted solar radiation (or light) and limiting indices of moisture, temperature and nutrients included (Charles-Edwards *et al.* 1986, Hammer *et al.* 1989).

GRASP combines these approaches and includes sensible biological limits calculated from radiation interception and nitrogen uptake. The combined approach has proved useful in modelling perennial native pastures in northern Australia (Day *et al.* 1993, 1997). A large number of pasture types have been parameterised using a minimum field data set method aimed at measuring as many of the 'functional' parameters (e.g. peak nitrogen yield) as possible. Thus calibration of relatively few parameters is only required. From the work of Day *et al.* (1997) average parameter sets have been developed (McKeon *et al.* 1998, Howden *et al.* 1998, Howden *et al*. 1999a,b) and used as a basis to apply GRASP at new sites in central Queensland (Yee Yet *et al.* 1999), top end of NT (Cafe *et al.* 1999) and Zimbabwe (Day *et al.* 1999).

Table 2b. Location and soil attributes used in GrassGro simulations. (N.B. Table continues over following 2 pages)

													Initial conditions					
Locality	BoM Station No.	Spp.	Soil No.	Soil name	wethers/ha	Depth (mm)	Field capacity (%)	Wilting point (%)	Bulk density (g/cm^3)	Ksat (mm/hr)	Evap parameter (mm^{o}C$^{-0.5}$)	Rooting depth (mm)	Soil moisture (%)	Live total biomass (kg/ha)	Dead standing (kg/ha)	Dead litter (kg/ha)	Below ground biomass (kg/ha)	Seed total (kg/ha)
Albury	72146	Phalaris	G30	Howlong	5.2	200	24	13	1.5	10	3.8	540	13	0	3600	520	3390	
						900	25	16	1.5	22			16					
Barraba	54003	Fescue		Cowra	5	200	20	9	1.5	22	3.5	540	14	1185	1260	234	2100	
						1000	28	12	1.5	3			20					
Bathurst	63005	Phalaris		OWRU	6.3	300	19	8	1.6	25	3.8	450	8	0	4300	440	4000	
						1000	35	22	1.32	1			22					
Bega	69002	Phalaris		Cowra	6.1	200	20	9	1.5	22	3.8	450	9	520	3890	800	3950	
						1000	28	12	1.5	3			12					
Braidwood	69010	Phalaris	as Bombala	M Keys	7.7	400	20	5	1.56	22	3.8	460	5	0	4000	100	3800	
				Granite		700	11	4	1.5	3			4					
Coolah	64025	Fescue	Forrest	Black	4.9	360	60	40	1.03	1	3.8	920	45	1160	950	365	1700	
						1500	56	41	1.14	1			46					
Cooma/ Monaro	70278	Phalaris	G33	Harden	5.5	310	22	9	1.57	27	3.6	460	9	0	1850	200	3000	
						900	27	20	1.5	0.8			20					
Coonabarabran	64008	Fescue		Cowra	5.2	200	20	9	1.5	22	3.5	540	14	1212	1520	260	2800	
						1000	28	12	1.5	3			20					
Cootamundra	73009	Phalaris	G31	Harden	5.2	180	25	9	1.63	8	3.8	410	9	0	4200	500	3500	
						900	22	10	1.5	11			10					
Cowra	63023	Phalaris		Cowra	5.6	200	20	9	1.6	22	3.8	450	9	0	3700	600	3500	
						1000	28	12	1.5	3			12					
Dubbo	65012	Annual		Cowra	6.5	200	20	9	1.5	22	3.5	440	14	260	2940	1220	410	500
						1000	28	12	1.5	3			20					
Goulburn	70263	Phalaris		OWRU	8.7	300	30	11	1.3	7	3.8	660	11	0	3700	450	4120	
						1000	41	31	1.48	1			31					
Grenfell	73014	Phalaris	G22	Grenfell	5.8	200	27	13	1.49	3	3.5	640	20	40	4050	650	3020	
						1000	27	19	1.4	1			24					
Gunnedah	55024	Fescue	Forrest	Black	4.3	360	60	40	1.03	1	3.8	920	45	800	1580	250	1950	
						1500	56	41	1.14	1			46					
Inverell	56017	Fescue		Cowra	6	200	20	9	1.5	22	3.5	540	14	2040	1400	290	2770	
						1000	28	12	1.5	3			20					
Lithgow	63224	Phalaris		Cowra/mod	8.9	150	27	17	1.54	3	3.8	540	24	870	2900	310	3600	
						600	35	23	1.5	0.8			35					

Table 2b continued. Location and soil attributes used in GrassGro simulations.

Locality	BoM Station No.	Spp.	Soil No.	Soil name	wethers/ha	Depth (mm)	Field capacity (%)	Wilting point (%)	Bulk density (g/cm³)	Ksat (mm/hr)	Evap parameter (mm°C⁻⁰·⁵)	Rooting depth (mm)	Initial conditions					
													Soil moisture (%)	Live total biomass (kg/ha)	Dead standing (kg/ha)	Dead litter (kg/ha)	Below ground biomass (kg/ha)	Seed total (kg/ha)
													45	1160	950	365	1700	
						1500	52	41	1.1	1			46					
Moss Vale	68045	Phalaris		Cowra	9.4	200	20	9	1.5	22	3.8	540	14	750	5610	747	5470	
						1000	28	12	1.5	3			20					
Mudgee	62021	Fescue		Cowra	5.1	200	20	9	1.5	22	3.8	540	14	1800	1200	320	2590	
						1000	28	12	1.5	3			20					
Orange	63231	Phalaris	CSIRO	Newbridge	8	200	37	16	1.42	27		580	16		4250	350	4450	
						600	39	27	1.5	1.3	3.8		27	0				
Parkes	65026	Annual		Cowra	7.7	200	20	9	1.5	22	3.5	440	14	0	4500	900	0	500
						1000	28	12	1.5	3			20					
Scone	61089	Fescue		Cowra	5.5	200	20	9	1.5	22	3.5	540	14	800	2290	370	2410	
						1000	28	12	1.5	3			20					
Temora	73038	Annual	G113	Temora	7.4	500	25	5	1.53	10	3.8	400	14	0	4500	900	0	500
						1000	29	22	1.64	2			25					
Tumut	72046	Phalaris		Cowra	7.1	200	20	9	1.5	22	3.8	540	9	0	4460	700	4600	
						1000	28	12	1.5	3			12					
Wellington	65035	Phalaris	G4 mod	Well&	4.8	100	29	16	1.6	13	3.8	570	22	155	4000	650	3660	
						900	30	18	1.43	1			24					
Wyalong	73054	Annual		Cowra	6.1	200	20	9	1.5	22	3.5	440	14	50	3020	1170	150	500
						1000	28	12	1.5	3			20					
Yass	70091	Phalaris	CSIRO	Bookham	7.5	400	23	7	1.5	22	3.8	540	7	0	3500	400	3770	
						600	38	33	1.5	0.8			33					
Young	73056	Phalaris	G31	Harden	5.9	180	25	9	1.5	8	3.8	540	9	0	3950	500	3620	
						900	22	10	1.5	11			10					
Binalong	73005	Phalaris		Bookham	7	400	23	7	1.5	22	3.8	540	7	500	4900	600	4560	
						600	38		1.5	0.8			33					
Condobolin	50052	Annual	G146		6.4	280	28	7	1.38	11	3.5	510	14	88	2290	770	200	500
						1000	29	18	1.48	3			24					
Coolamon	74033	Annual	G118	Wagga	6.3	150	25	6	1.5	13	3.8	450	14	80	3220	1070	270	500
						1000	33	23	1.48	1			28					
Crookwell	70025	Phalaris		Bombala	8.3	400	20	5	1.56	22	3.5	460	10	1700	4250	400	5100	
						700	11	4	1.5	0.8			9					

Table 2b continued. Location and soil attributes used in GrassGro simulations.

Locality	BoM Station No.	Spp.	Soil No.	Soil name	wethers/ha	Depth (mm)	Field capacity (%)	Wilting point (%)	Bulk density (g/cm^3)	Ksat (mm/hr)	Evap parameter (mm^{o}C$^{-0.5}$)	Rooting depth (mm)	Initial conditions: Soil moisture (%)	Initial conditions: Live total biomass (kg/ha)	Initial conditions: Dead standing (kg/ha)	Initial conditions: Dead litter (kg/ha)	Initial conditions: Below ground biomass (kg/ha)	Initial conditions: Seed total (kg/ha)
													14	1300	1600	290	2410	
						1000	28	12	1.5	3			20					
Echuca	80015	Phalaris		Harden	3.7	180	25	9	1.5	8	3.8	540	9		3950	500	3600	
						900	22	10	1.5	11			10					
Forbes	65016	Annual		Cowra	6.7	200	20	9	1.5	22	3.5	440	14	72	2600	1200	162	500
						1000	28	12	1.5	3			20					
Gilgandra	51018	Fescue		Cowra	4.3	200	20	9	1.5	22	3.5	540	14	930	1430	270	1790	
						1000	28	12	1.5	3			20					
Gundagai	73128	Phalaris	G116?	Wagga	5.8	120	28	18	1.57	11	3.8	510	18	0	3900	730	4000	
						1000	28	18	1.5	9			18					
Manilla	55031	Fescue		Lithgow thin mod	4.3	150	27	17	1.54	3	3.8	520	24	760	880	165	1410	
						600	41	29	1.5	0.8			35					
Nimmitabel	70067	Phalaris		Bombala	6.7	400	20	5	1.56	22	3.5	460	10	3000	1060	165	3800	
						700	11	4	1.5	0.8			7					
Singleton	61275	Fescue		cowra	5.3	200	20	9	1.5	22	3.5	540	14	1310	1940	380	2460	
						1000	28	12	1.5	3			20					
Tocumwal	74106	Phalaris	G31	Harden	4	180	25	9	1.5	8	3.8	540	9		3950	500	3620	
						900	22	10	1.5	11			10					
Tumbarumba	72043	Phalaris	G116?	Wagga	6.9	120	28	18	1.57	11	3.8	510	22	500	5150	520	5040	
						1000	28	18	1.5	9			24					
Lockhart	774064	Phalaris	12	2	4.9	370	24	6	1.56	31	3.8	460	6		3252	500	2950	
						1000	27	14	1.5	9			14					
Quirindi	755049	Fescue		Black Hamish	6	360	56	40	1.02	1	3.5	740	45	2000	1870	360	3100	500
						1500	54	41	1.1	1			46					

For temperate native pastures sites we have found that the simple 'growth index' approach alone was superior in terms of parameterisation to the combined approach used for perennial grasslands in northern Australia. In native tropical pastures the 'growth index' approach was used to model initial growth at the start of the growing season, and regrowth where frequent mowing or heavy grazing occurred (McKeon *et al*. 1980, Day *et al.* 1997). The 'growth-index' approach was used to model the whole season at temperate rangeland locations (including Canberra) by turning off the 'water use' approach (i.e. parameters for transpiration and radiation use efficiencies were set to zero).

Whilst the 'growth index' approach has proved suitable for situations where or when plant green cover is low or constant (e.g. swards with stoloniferous growth habit), it is likely to be inappropriate where green cover fluctuates rapidly from zero to 100% cover (e.g. high rainfall temperate pastures with high fertility). As a consequence GRASP ('spaghetti' version) was modified to allow the potential growth rate to change in response to changing green cover. Thus with the addition of one parameter the formulation using the growth index was expanded in GRASP to be similar but not identical to GrassGro. The representation of the effects of radiation interception are similar (Equation 27 in Moore *et al.* 1997).

7.4.2 Plant growth indices

The representation of temperature effects are similar but not identical (Figure 6 in Moore *et al.* 1997). In GRASP the temperature index is calculated directly for the average of daily maximum and minimum screen temperature. In GrassGro a lagged daytime temperature is calculated (Equation 8 and Figure 6 in Moore *et al.* 1997).

The temperature response curves are similar but not identical and hence the parameters controlling temperature response were investigated as described later. GRASP does not include the effects of radiation intensity on radiation use efficiency (Table 7 in Moore *et al.* 1997). The formulation of the soil moisture index is similar (Figure 6 in Moore *et al.* 1997) but there are substantial differences in representation of hydrology. In particular, GRASP does not include the restricting effects of waterlogging on growth (Figure 6 in Moore *et al.* 1997). GRASP being a sward model, does not include the effects of individual phenology of species but rather the general phenology of the whole sward. As described later, parameterisation of sward behaviour using nitrogen uptake has been the main way that restrictions on growth resulting from sward phenology (i.e. flowering and dormancy) has been represented in GRASP.

7.4.3 Soil moisture budget

The simulation of soil moisture is fundamental to both GRASP and GrassGro. However, different approaches have been adopted. GRASP simulates four layers (0-10 cm, 10-50 cm, 50-100 cm, and a fourth layer below 100 cm which is only available to trees). GrassGro simulates approximately 10 layers with varying thickness. GRASP specifies available moisture range in terms of upper and lower limits for each of the top three layers. In contrast, inputs to GrassGro include field capacity, wilting point, bulk density, Ksat and rooting depth. Analysis of simulated soil moisture values from GrassGro indicated that simulated soil moisture exceeds field capacity at some locations (7 out of 44) for a relatively high proportion of time (>20%). In GRASP no internal drainage is modelled below the specified upper limit and all drainage, when moisture exceeds field capacity, occurs in a single day.

7.4.3.1 Runoff

Runoff in GRASP is an empirical function of cover, rainfall intensity and soil moisture deficit (Scanlan *et al.* 1996). GrassGro uses the more popular 'curve number' approach. However, it is not clear to what extent the effect of cover is treated the same. The GRASP approach results in low runoff when surface cover is high whilst the 'curve number' approach allows runoff to occur under high cover conditions. GRASP has no interception store whilst GrassGro has both sward interception and surface moisture stores.

7.4.3.2 Soil evaporation

In GRASP soil evaporation occurs from the top two layers (0-10 cm and 10-50 cm). Pasture dry matter (green, standing dead and litter) reduces potential soil evaporation to zero at 10,000 kg/ha. Preliminary simulations in the temperate high rainfall zone with GRASP indicated that soil evaporation was likely to be an important component of the soil water budget. In contrast, GrassGro includes an interception store and a surface store. The formulation of soil evaporation is different to GRASP and the effects of cover also appear to be fundamentally different. As a result a major stage in the parameterisation was to test whether these different formulations affected the calibration of GRASP.

7.4.3.3 Potential evapotranspiration

In GRASP, Class A pan is taken as potential evapotranspiration. This view is supported by (1) lysimeter studies in southern and northern Australia (e.g. Rose *et al.* 1972); and (2) extensive testing of the model with measured field data (wheat crops in W.A., K. Rickert personal communication; and 160 site x year combinations of tropical native pasture exclosures providing 728 soil moisture observations, Day *et al*. 1997).

GrassGro appears to assume that potential evapotranspiration is 0.8 of Class A Pan (Moore *et al.* 1997, p. 540). The GrassGro approach has also been used in several other modelling studies. Thus the models calculate different values of transpiration when there is 100% green cover and high soil moisture.

Where seasonal potential evaporative demand greatly exceeds seasonal rainfall, soil moisture budget models are likely to be less sensitive to variation in potential evapotranspiration than in situations of low evaporative demand and high rainfall, e.g. temperate pastures in winter.

The major differences in the soil moisture budgets would be expected to appear in the internal drainage and evapotranspiration. As indicated above, GrassGro simulates soil moisture values above field capacity allowing both the processes of delayed drainage and evapotranspiration to occur simultaneously. Thus the components of the soil water budget are unlikely to be identical in GRASP and GrassGro.

7.4.4 Plant senescence

Death of green material in GRASP occurs due to age, water stress and frost. Similar processes of age and frost occur in GrassGro, however, GrassGro includes 'tissue pools' defined in terms of digestibility. Death of green tissue 'is modelled as a constant specific rate and is therefore low and relatively constant during the growing season and rises sharply at the end' (Moore *et al.* 1997, p. 554). In GRASP, soil moisture is used to determine the maximum green cover that can be supported each day. Thus the two models represent the impact of soil moisture on senescence quite differently.

7.4.5 Detachment, trampling and litter decomposition

In GRASP, detachment is calculated using different rates (proportion per day) for leaf and stem, and time of the year (1 December to 30 April and 1 May to 30 November). In spaghetti GRASP the effects of rainfall accelerating detachment have been included and parameterised for ephemeral species at Alice Springs. Trampling is calculated relative to animal intake. In GrassGro detachment is a function of rainfall and 'herbivore weight'. Thus similar factors are included in calculating detachment but algebraic representation is different. The version of GRASP used in Aussie GRASS does not as yet include the effects of rainfall on detachment.

In both models litter decomposition is a function of moisture and temperature. Based on comparison of pools litter is usually lower than dead SDM indicating that detachment (rather than litter decomposition) is more likely to be the rate limiting process.

7.4.6 Animal intake

In GRASP, potential dry matter intake by sheep is a constant (400 kg per year for a dry sheep equivalent (DSE), i.e. 45 kg liveweight). However seasonal variation is calculated for the intake of cattle as function of potential seasonal live weigh gain (LWG). Selection occurs between green and dead pasture with strong preference for green material. Selection parameters vary for sheep and cattle allowing sheep to more readily select green material (Hall 1996). Dry matter intake is restricted linearly below a threshold of pasture SDM (50 to 500 kg/ha for rangeland and tropical pastures). GrassGro has a more sophisticated model of animal intake allowing for seasonal and yearly variation in digestibility, nutritional demand and supplementation. As described later, different approaches were adopted in the calibration than would be used in simulation to overcome these differences between the models.

7.4.7 Nutrient availability and high plant production

Because GRASP was developed at locations where nutrient availability limits plant growth much of the time, a simple nutrient uptake model of nitrogen has been used to calculate uptake and 'nitrogen concentration' in plant growth. This index of nutrient availability is used to limit growing-season plant growth once both maximum uptake has occurred and minimum concentration of nitrogen has been reached.

Nitrogen uptake is calculated as a function of transpiration for each year from the start of the growing season (which varies with location). Because the GrassGro simulation used here did not include nutrient availability explicitly, the simulated growth has been converted to estimate nitrogen uptake assuming a concentration of 0.88%N throughout the growing season. This value is the average of samples taken from temperate rangeland C_3 sites. This approach allows parameterisation of nutrient uptake in GRASP from the simulations of GrassGro and allows GRASP to represent phenological restrictions on plant growth at the end of the growing season. In other applications GrassGro has been used to explore the effect of nutrient availability (Simpson *et al.* 2000).

Preliminary examination of GrassGro output indicated annual growths as high as 15,000 to 20,000 kg DM/ha with green SDM of 8,000 kg/ha. The reality of these values is currently being reviewed and GrassGro simulations may be repeated. Nevertheless, for a conservative nitrogen concentration in dry matter (0.88% N), such growth would require annual uptake of 130 to 180 kg N/ha and the green pool would represent 70kg N/ha at peak yield. In fact higher values are likely since 0.88%N was derived from situations of low fertility. Similar high values of annual growth have been measured for kikuyu in south-east Queensland (J.O. Carter personal communication) and the rapid decay of dead material that occurs in these pastures probably contributes to the annual turnover of nitrogen needed to maintain high growth rates.

A major concern in the use of GRASP is that we have had limited experience in modelling grazing trials with the high levels of plant productivity simulated by GrassGro. Most of the previous work of this type with GRASP has concentrated on forage crop field trials where there has been little removal or detachment of material and hence growth parameters could be reliably determined from field data.

GRASP has also been applied to high production dairy pastures in northern Queensland (Atherton Tablelands, Mayer 1982). In this case, sub-models of high senescence rates due to shading and rapid decay rates of dead material were required to simulate observed pools of green and the observed absence of dead material in the pasture. However, these features are no longer available in the Aussie GRASS or spaghetti versions and hence are not available for the parameterisation of high rainfall - high fertility temperate pastures.

7.4.8 Summary

The models include similar physical and biological processes but have algebraic formulations that are sufficiently different that the same parameters (e.g. temperature response) cannot be used. Furthermore there are several important differences in some of the processes that are not common to both models (drainage, nutrient availability). Hence the models are certainly not identical and the following parameterisation of GRASP represents a procedure to cope with (1) different formulations of the same physical/biological processes; and (2) different processes occurring with unknown frequency at different locations.

7.5 Calibration strategy

Preliminary calibration was conducted for six phalaris sites in April 2000 using the PEST calibration software (Doherty 2001) and a spaghetti GRASP version which was customised for this procedure. Major findings of the preliminary study were:

1. the importance of including pasture growth and intake as well as dry matter pools when calibrating parameters;
2. sensible parameter values were found even with restricted parameter sets;
3. need for simulated soil water data as well as plant pools; and
4. need for rainfall effect on detachment of green material.

Based on the preliminary experience new files were prepared for 44 sites including simulation output of soil moisture. GrassGro outputs of pastures and soil moisture data were converted into formats used by spaghetti GRASP.

Monthly values from 1957 to 2000 of green, standing dead and litter pools and soil moisture data were stored along with annual accumulated pasture growth and intake. Accumulated values were set to zero on 1 February each year.

7.5.1 Stocking rate management

The GrassGro simulations were carried out with a constant stocking rate over the 43 years. In GrassGro seasonal and year-to-year differences in pasture quality and quantity result in year-to-year variability in annual intake despite a constant stocking rate. Since GRASP assumes a constant intake, as long as pasture SDM is not limiting, a different 'stocking rate' was calculated for each year by converting GrassGro output to the equivalent GRASP DSE stocking rate assuming a DSE eats 400 kg DM per year (Table 3). For most locations (37/44) the coefficient of variation of annual stocking rate was less than 10% (Table 3).

Preliminary investigation of GrassGro output indicated that intake declined (approximately linearly) when pasture SDM was below 1,000 kg/ha (Figure 13). Daily GrassGro output of pasture SDM was used to correct GRASP DSE stocking rate calculated above. Using this approach of varying the stocking rate each year minimised the impact of variation in intake on the parameterisation of processes of dry matter flow.

The parameterisation of GRASP to simulate the seasonal and annual variation in intake modelled by GrassGro is the subject of a further study although considerable work has already been done by Hall (1996) in evaluating GrazFeed (animal model in GRAZPLAN) for Queensland pastures and Hall's analysis will be the basis for future work in Aussie GRASS.

7.5.2 Soil moisture parameters

Analysis of GrassGro output indicated that soil moisture was above the nominated field capacity for a considerable proportion of the time (Table 4). The upper limits of soil moisture used in GRASP were derived from GrassGro output by:

1. averaging soil moisture values for days above field capacity; and
2. multiplying these average values by 1.10 (i.e. increase of 10%).

The lower limits were similarly set by averaging days below the nominated wilting point and multiplying by 0.90 (i.e. a decrease of 10%). Preliminary testing found that this procedure allowed GRASP to simulate GrassGro soil moisture reasonably well.

Table 3. Average and range in annual stocking rates (SR, DSE/ha) used in calibration procedure of GRASP. GrassGro simulations were conducted with constant stocking rate but intake varied seasonally and annually depending on pasture quality. Hence, stocking rate was changed annually in GRASP simulations to achieve the same intake of pasture simulated by GrassGro. Average stocking rate, standard deviation, minimum and maximum over the 43-year period and GrassGro constant stocking rate are shown.

Location	Spp.	Average SR (DSE/ha)	SR stand. dev.	CV (%)	SR minimum (DSE/ha)	SR maximum (DSE/ha)	GrassGro SR (wethers/ha)
Albury	Phalaris	6.04	0.17	2.9	5.7	6.5	5.2
Barraba	Phalaris	7.23	0.39	5.4	5.7	8.1	6.3
Bathurst	Fescue	5.47	0.61	11.1	4.0	6.3	5.0
Bega	Phalaris	7.04	0.38	5.3	6.0	7.6	6.1
Binalong	Phalaris	8.16	0.22	2.7	7.8	8.6	7.0
Braidwood	Phalaris	8.92	0.40	4.4	8.2	9.8	7.7
Condobolin	Annual	6.95	0.57	8.1	5.2	7.7	6.4
Coolah	Fescue	5.04	0.64	12.7	3.2	6.1	4.9
Coolamon	Annual	6.88	0.54	7.9	5.2	7.6	6.3
Cooma/Monaro	Phalaris	6.33	0.37	5.8	5.0	7.0	5.5
Coonabarabran	Fescue	5.82	0.45	7.7	4.5	6.5	5.2
Cootamundra	Phalaris	6.04	0.22	3.7	5.2	6.4	5.2
Cowra	Phalaris	6.46	0.27	4.2	5.8	7.1	5.6
Crookwell	Phalaris	9.49	0.33	3.5	9.1	10.6	8.3
Dubbo	Annual	7.20	0.57	8.0	5.5	8.0	6.5
Dunedoo	Fescue	5.12	0.66	13.0	3.2	6.0	4.8
Echuca	Phalaris	4.07	0.25	6.2	3.1	4.6	3.7
Forbes	Annual	7.38	0.65	8.8	5.4	8.3	6.7
Gilgandra	Fescue	4.16	0.68	16.4	2.5	5.2	4.3
Goulburn	Phalaris	9.94	0.41	4.2	9.3	11.1	8.7
Grenfell	Phalaris	6.64	0.34	5.1	5.2	7.3	5.8
Gundagai	Phalaris	6.77	0.14	2.1	6.4	7.1	5.8
Gunnedah	Fescue	4.14	0.61	14.8	2.2	5.1	4.3
Inverell	Fescue	6.85	0.49	7.1	5.2	7.5	6.0
Lithgow	Phalaris	10.33	0.31	3.0	9.7	11.0	8.9
Lockhart	Phalaris	5.63	0.20	3.6	5.1	6.0	4.9
Manilla	Fescue	4.22	0.71	16.8	2.3	5.2	4.3
Merriwa	Fescue	5.70	0.49	8.6	4.1	6.4	5.2
Moss	Phalaris	10.91	0.36	3.3	10.3	12.0	9.4
Mudgee	Fescue	5.78	0.55	9.5	4.0	6.4	5.1
Nimmitabel	Phalaris	7.83	0.30	3.8	7.0	8.5	6.7
Orange	Phalaris	9.26	0.32	3.5	8.5	10.1	8.0
Parkes	Annual	8.66	0.62	7.1	6.8	9.5	7.7
Quirindi	Fescue	6.61	0.48	7.2	5.4	7.4	6.0
Scone	Fescue	6.08	0.64	10.5	3.4	6.9	5.5
Singleton	Fescue	5.86	0.53	9.0	3.7	6.5	5.3
Temora	Annual	8.26	0.45	5.5	7.0	9.1	7.4
Tocumwal	Phalaris	4.45	0.30	6.8	3.2	4.9	4.0
Tumbarumba	Phalaris	8.04	0.22	2.7	7.5	8.7	6.9
Tumut	Phalaris	8.35	0.19	2.3	7.9	9.0	7.1
Wellington	Phalaris	5.53	0.26	4.7	4.9	5.9	4.8
Wyalong	Annual	6.53	0.62	9.4	4.8	7.3	6.1
Yass	Phalaris	8.72	0.32	3.6	8.1	9.8	7.5
Young	Phalaris	6.84	0.27	4.0	6.1	7.5	5.9

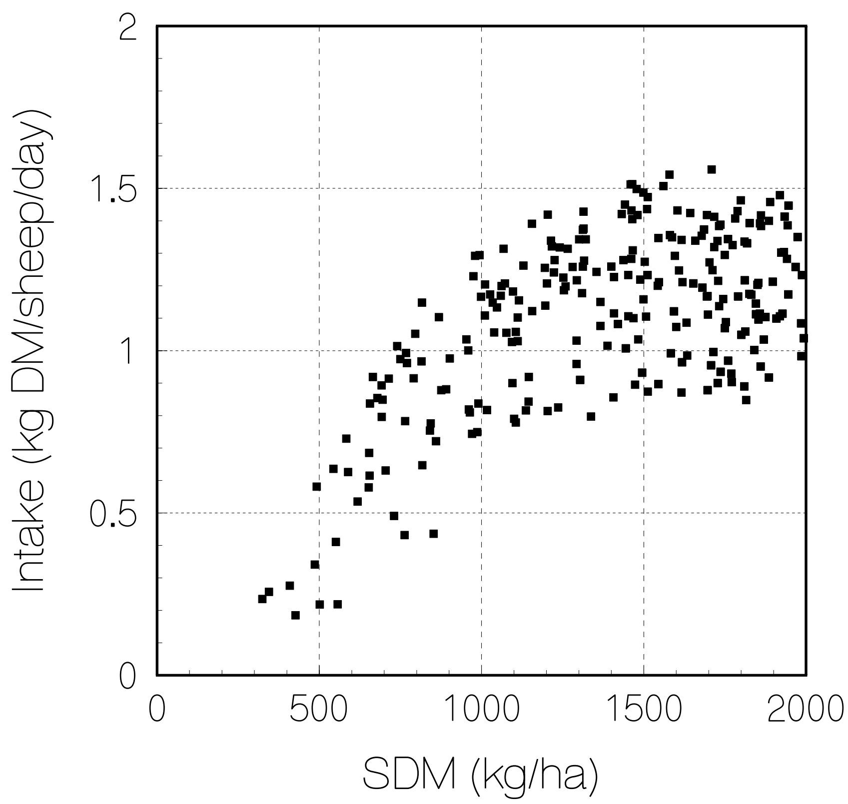


Figure 13. The relationship between total standing dry matter (SDM, kg/ha) and animal intake (kg DM/sheep/day) for 6 locations and selected years. Values are from preliminary GrassGro simulations (April 2000).

7.5.3 Parameter sets and calibration stages

7.5.3.1 Stage 1

A base set of plant/soil parameters was derived from the average set previously used in spatial and other studies (McKeon *et al*. 1998, Hall *et al*. 1998, Howden *et al*. 1999a,b, Cafe *et al.* 1999, Yee Yet *et al.* 1999).

Soil moisture parameters (upper and lower limits) were derived as described above. Based on the comparison of models reviewed above, 22 parameters representing the major hydrological and biological processes were calibrated. Values were constrained between sensible limits (Table 5). In Stage 1 of the calibration procedure, some parameters were estimated directly from combined GrassGro and GRASP output (e.g. nitrogen uptake) allowing other values to be found by calibration. Different weightings (Table 6) were given to different variables during this stage. This procedure controlled the process of calibration and provided insight into the major sources of uncertainty (detachment and plant water use). Stage 1 also allowed initial values to be better estimated for later stages.

Table 4. Analysis of upper and lower limits of soil moisture simulated by GrassGro. Field capacity (FC) and wilting point (WP) values were as given in Table 2b. Indicative saturation values (SATeq) were calculated from bulk density values using the formula of Littleboy (1997). Average soil moisture was calculated for the days when simulated soil moisture exceeded field capacity (Ave. max.) and were below wilting point (Ave. min.). The daily maximum (Day max.) and minimum (Day min.) soil moisture, percentage of days greater than field capacity (%ds>FC) and percentage of days less than wilting point (%ds<WP) over the 43 years of simulation are also shown.

Location	BoM station No.	SATeq (mm)	FC (mm)	Ave. max. (mm)	Day max. (mm)	%ds>FC	WP (mm)	Ave. min. (mm)	Day min. (mm)	%ds<WP	No. days
Albury	72146	206	123	129	161	16.1	74	73	71	1.0	15796
Barraba	54003	206	124	134	203	6.9	54	54	52	0.2	15796
Bathurst	63005	208	127	136	207	17.2	75	74	73	0.6	15796
Bega	69002	206	124	137	197	11.2	62	0	62	0.0	15796
Binalong	73005	206	130	138	210	15.1	28	0	60	0.0	15796
Braidwood	69010	198	91	103	196	11.0	27	26	25	2.5	15796
Condobolin	50052	220	142	151	192	3.5	59	59	58	2.7	15800
Coolah	64025	285	294	0	232	0.0	201	201	198	13.1	15796
Coolamon	74033	209	153	162	200	13.6	95	94	94	1.3	15800
Cooma/ Monaro	70278	198	120	129	194	12.1	69	68	65	5.4	15796
Coonabarabran	64008	206	124	135	202	11.1	54	53	53	0.2	15796
Cootamundra	73009	198	115	123	156	16.2	59	59	59	0.5	15796
Cowra	63023	199	124	133	189	16.1	62	0	63	0.0	15796
Crookwell	70025	198	91	106	189	29.7	27	26	25	1.6	15796
Dubbo	65012	206	124	133	194	8.8	64	63	62	0.1	15830
Dunedoo	64009	206	124	134	189	6.8	54	54	53	0.2	15796
Echuca	80015	206	115	123	163	6.0	48	48	47	0.4	15796
Forbes	65016	206	124	133	187	8.7	64	63	63	0.1	15800
Gilgandra	51018	206	124	134	184	6.1	54	54	54	0.1	15796
Goulburn	70263	229	172	181	228	10.7	95	94	93	2.2	15796
Grenfell	73014	218	135	153	200	26.4	83	82	81	2.3	15796
Gundagai	73128	203	140	147	176	19.0	90	90	89	0.7	15796
Gunnedah	55024	285	294	0	230	0.0	201	201	196	10.6	15796
Inverell	56017	206	124	134	204	7.8	54	54	53	0.2	15796
Lithgow	63224	204	163	173	203	26.6	106	106	105	0.7	15796
Lockhart	74064	198	124	128	153	5.4	46	0	46	0.0	15796
Manilla	55031	204	184	189	204	3.5	127	126	125	1.7	15796
Merriwa	61040	288	274	276	281	0.2	201	201	196	11.5	15796
Moss Vale	68045	206	124	136	205	16.7	54	0	55	0.0	15796
Mudgee	62021	206	124	133	178	10.8	54	53	50	0.6	15796
Nimmitabel	70067	198	91	104	195	21.2	27	26	24	1.9	15796
Orange	63231	212	191	194	212	9.7	113	112	111	1.6	15796
Parkes	65026	206	124	133	194	11.9	64	0	64	0.0	15796
Quirindi	55049	288	277	278	279	0.4	201	200	195	9.1	15796
Scone	61089	206	124	134	196	6.4	54	53	52	0.4	15796
Singleton	61275	206	124	135	199	6.7	54	54	54	0.1	15796
Temora	73038	201	125	132	164	8.3	32	0	38	0.0	15796
Tocumwal	74106	206	115	122	160	7.6	48	48	47	0.1	15796
Tumbarumba	72043	203	140	148	179	28.9	90	89	88	1.2	15796
Tumut	72046	206	124	138	196	30.1	54	0	55	0.0	15796
Wellington	65035	213	149	161	205	20.4	88	87	87	1.5	15796
Wyalong	73054	206	124	133	200	7.9	64	64	64	0.1	15800
Yass	70091	206	130	137	204	11.4	61	61	60	1.0	15796
Young	73056	206	115	124	169	15.7	48	48	47	0.4	15796

Table 5. Parameters and description used to calibrate GRASP to GrassGro output using the PEST calibration software (Doherty 2001). Several parameters were 'tied' where they represented upper and lower co-ordinates of function (e.g. frost effects). Starting values were estimated from Table 2a, from manual calibration and interpretation from GrassGro output. Upper and lower bounds were set to provide sensible constraints to parameters. Bounds for P045 and P061 to P064 were changed at later stages of the calibration procedure.

Parameter number	Description	Starting value	Upper bound	Lower bound
p045	Green yield (kg/ha) when green cover for transpiration is 50%	900	100	10000
p046	Green yield (kg/ha) when radiation interception is 50%	900	100	2000
p149	Soil water index at which above-ground growth stops	0.25	0.01	0.99
p006	Potential daily regrowth rate (kg DM/ha/day/unit of density)	10	1	100
p307	Radiation use efficiency of intercepted solar radiation (kg DM/ha per MJ/m^2)	6	1	20
p098	N uptake per 100 mm of pasture transpiration	50	1	100
p099	Maximum N uptake (kg/ha)	100	50	200
p009	Soil water index needed for maximum green cover	0.25	0.01	0.99
p010	Death rate at zero soil water stress (kg/kg/day)	0.002	0.001	0.99
p051	Additional death (kg/kg/day) per unit of water stress	0.013	0.001	0.998
p011	Minimum screen temperature (^{o}C) at which green cover = 0%	-4	-15	-3
p125	Minimum screen temperature (^{o}C) at which green cover = 100%	-3.2	-15	-3
p128	Proportion of dead leaf detached per day from 1 Dec to 30 April	0.004	0.000001	1
p130	Proportion of dead leaf detached per day from 1 May to 30 November	0.004	0.000001	1
p154	Proportion of dead leaf detached per day per 100 mm of (rain - p156)	0.1	0.000001	1
p156	Two-day rainfall required to initiate detachment caused by rain	25	1	200
p015	Proportion of pasture which can be eaten by stock	0.75	0.000001	1
p144	SDM (kg/ha) at which intake restriction no longer operates	1000	200	1500
p061	Temperature below which temperature index (TIX) is zero	3	0.01	5
p062	As temperature increases from P0631to P062, TIX increases from 1 to 0.0	10	5.1	10
p063	As temperature increases from P062 to P063, TIX remains at 1	20	10.1	20
p064	As temperature increases from P063 to P064, TIX decreases from 1 to 0.0	30	20.1	40

Table 6. Final weightings used for soil moisture and pasture variables in the calibration procedure. The different weighting reflected both different units of the variables, their relative importance and the likely difficulty in calibration.

Model Variable	Weighting
green (kg DM/ha)	3
standing dry matter (kg/ha)	2
accumulated * monthly pasture growth (kg DM/ha)	1
accumulated * monthly pasture intake (kg DM/ha)	3
soil moisture 0-50 cm (mm)	10
litter (kg DM/ha)	0.5

* accumulated values set to zero 1 Feb each year

7.5.3.2 Stage 2

A large number (22) of parameters (Table 5) were calibrated. The weightings (Table 6) given to pasture and soil moisture variables reflected the results of Stage 1 which showed that the simulation of green SDM had the lowest agreement with GrassGro output.

7.5.3.3 Stage 3

To test whether high values of pasture growth and SDM were contributing too much to the calibrated values, GrassGro output data for pasture SDM and accumulated growth greater than 10,000 kg/ha were not considered in the calibration procedure's objective function.

7.5.3.4 Stage 4

The parameters for soil evaporation and litter decomposition were added to the calibration procedure (25 parameters) to further evaluate the impact of the different representation of hydrological processes, e.g. soil evaporation.

7.5.3.5 Stage 5

The role of evaporative demand was examined by reducing the number of biological parameters and concentrating on parameters controlling hydrological processes such as evapotranspiration (19 parameters).

Thus the overall strategy was one of 'constrained' exploration with expansion of the number of parameters and their constraining bounds. Further stages concentrated on those areas which appeared to have greater uncertainty (hydrological processes) in comparing the models.

7.5.4 Weightings of pasture variables

Monthly accumulating variables (pasture growth and intake) were used as part of the calibration procedure and were designed to provide extra weighting (Table 6) to the seasonal distribution of growth and intake during autumn/winter and spring and reduce the impact of high spring/summer growths on the parameterisation procedure. Not surprising, the major sources of disagreement appeared to occur during this period although, as will be discussed, not greatly affecting the correlations between pasture growth from the models. There has been insufficient time to consult with NSW Agriculture as to the implications of these weightings. However, opportunity exists to formulate new weightings should it be desired to give more emphasis to either low or high growth years.

7.5.5 Data sets

The 44 locations were treated in 5 groups because of species differences (Table 2a,b) and to increase the efficiency of the calibration procedure. Group 1 was a set of 6 phalaris locations chosen to represent a wide range of geographical and climatological locations. Group 2 had the remaining 18 phalaris locations and provided a dataset to test for independent validation of the parameters calibrated in Group 1. Group 3 had 10 fescue locations. Group 4 contained all the annual ryegrass locations.

Group 5 had 3 sites (Gunnedah, Coolah and Merriwa) with very high field capacities and wilting points. Preliminary testing on these sites indicated that a more detailed examination of hydrology would be required and hence the 3 sites were not included in the calibration procedure. Quirindi with similar soil characteristics was included in the fescue set (Group 3).

7.6 Results

Results for 41 locations (i.e. excluding Group 5) for Stages 2 and 3 with 22 parameters calibrated are described in detail. A standard period from 1960 to 1999 was chosen to allow for a 'spin up' period (1957 to 1959) and to remove variation in data availability for the year 2000. Table 7 gives the calibrated values for Stages 2 and3. For phalaris there was little effect of excluding accumulated growth values and pasture SDM greater than 10,000 kg/ha. For fescue and annual ryegrass there were differences in frost response but growth parameters were consistent for both stages of calibration. Time series of simulation for each location are shown in Appendix 2.

The calibrated values for a few parameters were at or close to the upper or lower bounds which had been set to constrain the calibration (Table 5 and 7). Several of the bounds were regarded as 'not negotiable', having been derived from independent interpretation of GrassGro output (e.g. nitrogen uptake) or from parameters set as input to GrassGro (temperature response).

Of major concern was the value found for p045 (Table 7), i.e. 'green yield at which potential transpiration is 50% of Class A pan'. In previous studies with GRASP (Day *et al*. 1997), p045 and p046 ('green yield for 50% of radiation interception') have had similar values as would be expected. Indeed the preliminary investigations in April 2000, when soil moisture data were not available, and higher available water ranges were used, the calibrated values of p045 were similar to both p046 and to values indicated in the GrassGro input file (Table 2a). The high value calibrated for p045 causes reduced transpiration. The implication of this result was explored in Stages 4 and 5 to be reported later.

Tables 8a-d and Figures 14a-c show correlation (R^2) values for each location at the various calibration stages. High R^2 are to be expected for the annually accumulated variables of pasture growth and pasture eaten because of the effect of accumulating time. Nevertheless R^2 values are presented here for completeness.

7.6.1 Pasture growth

Inspection of individual years for each location (Appendix 2) indicates that GRASP represents the pattern of seasonal and year-to-year variation reasonably well accounting for 60 to 70% of variation in annual growth across location and years (Figure 15 Table 9). For the six phalaris sites, GRASP was unable to simulate the high annual growths of the early 1960s at Bega and Goulburn (Appendix 2).

Table 7. Parameter values resulting from each stage of the calibration of GRASP. Some parameter values (shown in italics) were set constant for particular stages of the calibration procedure. Parameter names and examples of upper and lower bounds have been given in Table 5. The number of parameters calibrated for Stages 2, 3, 4 and 5 were 22, 22, 25 and 19 respectively.

Paramete	**Phalaris**				**Fescue**				**Annual ryegrass**			
r	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
p045	2000.0*	2000.0*	3000.0*	2816.1	2000.0*	1964.3	2079.0	2249.1	2000.0*	2000.0*	3000.0*	3550.8
p046	1039.6	986.3	1070.3	362.2	675.1	631.6	679.9	691.0	1136.1	1172.4	1980.041	1310.2
p149	0.235	0.254	0.540	0.645	0.0770	0.1769	0.2209	0.0224	0.161	0.155	0.2479911	0.5403
p006	32.6	31.7	32.9	34.6	26.3	30.6	31.4	26.0	37.7	37.2	40.4675	40.0
p307	5.0	4.7	4.6	4.1	4.5	4.4	4.6	3.8	7.4	7.2	9.406396	6.7
p098	50.0*	50.0*	50.0*	*50.0*	50.0*	50.0*	50.0*	*50.0*	50.0*	50.0*	50	*50.0*
p099	195.8	200.0*	200.0*	*200.0*	200.0*	101.6	200.0*	*200.0*	200.0*	200.0*	92.64751	*200.0*
p009	0.2815	0.2398	0.4723	0.4949	0.1740	0.2266	0.2374	0.2909	0.1092	0.1124	0.166429	0.3686
p010	0.0015	0.0010	0.0010	0.0012	0.0061	0.0065	0.0067	0.0043	0.0017	0.0012	0.001	0.0011
p051	0.0318	0.0437	0.0543	0.0504	0.0146	0.0137	0.0162	0.0260	0.033	0.0325	0.04055408	0.0550
p011	-8.5	-8.5	-8.6	-8.6	-15.0	-4.8	-4.6	-13.5	-13.8	-9.0	-8.498604	-8.3
p125	-6.8	-6.8	-6.9	-6.9	-12.0	-3.8	-3.7	-10.8	-11.1	-7.2	-6.798883	-6.6
p128	0.0058	0.0064	0.0058	0.0060	0.0040	0.0058	0.0059	0.0046	0.0053	0.0060	0.00630527	0.0042
p130	0.0048	0.0050	0.0048	0.0072	0.0093	0.0079	0.0076	0.0095	0.0057	0.0057	0.00776004	0.0070
p154	0.0742	0.0467	0.0572	0.0077	0.0315	0.0019	0.0194	0.0072	0.1485	0.1521	0.1326234	0.1154
p156	1.0*	1.0*	1.0*	*0.0*	6.1	109.3	6.9	*0.0*	3.6	7.5	10.60968	*0.0*
p015	1.0*	1.0*	1.0*	*1.0*	1.0*	1.0*	1.0*	*1.0*	1.0*	1.0*	1.0*	*1.0*
p144	1101.0	1236.7	1004.7	*1000.0*	1500.0*	1488.3	1420.8	*1000.0*	1500.0*	1500.0*	1003.68	*1000.0*
p061	1.8	0.4	0.4	5.0	7.0	7.0	7.0	8.0*	7.0	6.9	6.4637	5.0*
p062	8.0*	8.0*	8.0*	6.3	11.1	11.2	11.9	10.0	8.2	8.1	9.32872	10.0*
p063	16.0*	16.0*	16.0*	14.3	16.0*	16.2	16.6	18.7	16.0*	16.0*	16.0*	18.7
p064	26.0*	26.0*	26.0*	20.1*	26.0*	26.0*	26.0*	23.2	26.0*	26.0*	26.0*	21.5
p033			9.4	15.0			2.1	2.8			3.556763	2.3
p016			0.070059	0.076907			0.116242	0.061243			0.052712	0.070334
p018			0.000181	*0.0*			0.000001	*0.0*			0.003224	*0.0*

* calibrated parameters at bounds

Table 8a. Stage 2 correlation co-efficient (R^2) between GrassGro and calibrated GRASP simulations for soil moisture (0-50cm) and pasture variables; green and total standing dry matter, accumulated monthly pasture growth and animal intake (set to zero 1 Feb each year). Stations are sorted within each group according to their BoM station number.

Location	BoM station No.	Green SDM	Total SDM	Accumulated growth	Accumulated intake	Soil water
			Phalaris optimisation set			
Bathurst	63005	0.52	0.68	0.92	0.95	0.72
Wellington	65035	0.66	0.67	0.92	0.98	0.68
Bega	69002	0.42	0.44	0.82	0.97	0.76
Goulburn	70263	0.65	0.74	0.95	0.99	0.75
Cooma	70278	0.33	0.62	0.94	0.98	0.69
Albury	72146	0.84	0.79	0.95	0.99	0.85
			Phalaris validation set			
Cowra	63023	0.69	0.71	0.92	0.97	0.71
Lithgow	63224	0.40	0.57	0.94	1.00	0.77
Orange	63231	0.53	0.68	0.94	0.99	0.84
Moss Vale	68045	0.49	0.67	0.96	1.00	0.74
Braidwood	69010	0.48	0.69	0.94	0.99	0.77
Crookwell	70025	0.51	0.66	0.93	1.00	0.78
Nimmitabel	70067	0.35	0.67	0.94	0.99	0.74
Yass	70091	0.64	0.70	0.93	0.98	0.78
Tumbarumba	72043	0.60	0.66	0.93	0.99	0.76
Tumut	72046	0.71	0.71	0.95	1.00	0.82
Binalong	73005	0.69	0.71	0.94	0.99	0.73
Cootamundra	73009	0.78	0.75	0.93	0.97	0.80
Grenfell	73014	0.81	0.79	0.94	0.96	0.78
Young	73056	0.73	0.70	0.92	0.98	0.82
Gundagai	73128	0.81	0.79	0.94	0.99	0.72
Lockhart	74064	0.79	0.73	0.95	0.97	0.76
Tocumwal	74106	0.76	0.69	0.92	0.96	0.84
Echuca	80015	0.80	0.71	0.93	0.96	0.85
			Fescue			
Gilgandra	51018	0.75	0.64	0.90	0.97	0.84
Barraba	54003	0.62	0.63	0.93	0.99	0.78
Manilla	55031	0.67	0.62	0.90	0.97	0.78
Quirindi	55049	0.60	0.60	0.92	0.98	0.73
Inverell	56017	0.63	0.71	0.93	0.99	0.80
Scone	61089	0.72	0.68	0.93	0.99	0.79
Singleton	61275	0.59	0.54	0.90	0.99	0.82
Mudgee	62021	0.72	0.75	0.94	0.99	0.84
Coonabarabran	64008	0.72	0.77	0.95	0.99	0.79
Dunedoo	64009	0.73	0.71	0.94	0.98	0.81
			Annual			
Condobolin	50052	0.66	0.75	0.92	0.97	0.73
Dubbo	65012	0.69	0.77	0.91	0.97	0.78
Forbes	65016	0.72	0.77	0.90	0.96	0.78
Parkes	65026	0.68	0.78	0.92	0.97	0.75
Temora	73038	0.72	0.78	0.94	0.98	0.85
Wyalong	73054	0.68	0.69	0.86	0.95	0.81
Coolamon	74033	0.71	0.76	0.90	0.97	0.86

Table 8b. Stage 3 correlation co-efficient (R^2) between GrassGro and calibrated GRASP simulations for soil moisture (0-50cm) and pasture variables; green and total standing dry matter, accumulated monthly pasture growth and animal intake (set to zero 1 Feb each year).

Location	BoM station No.	Green SDM	Total SDM	Accumulated growth	Accumulated intake	Soil water
			Phalaris optimisation set			
Bathurst	63005	0.56	0.69	0.91	0.95	0.72
Wellington	65035	0.66	0.65	0.91	0.98	0.69
Bega	69002	0.39	0.45	0.82	0.97	0.76
Goulburn	70263	0.66	0.74	0.95	0.99	0.75
Cooma	70278	0.34	0.62	0.93	0.98	0.69
Albury	72146	0.84	0.77	0.95	0.99	0.85
			Phalaris validation set			
Cowra	63023	0.69	0.69	0.92	0.97	0.71
Lithgow	63224	0.40	0.59	0.94	1.00	0.76
Orange	63231	0.56	0.67	0.94	0.99	0.84
Moss Vale	68045	0.50	0.69	0.96	1.00	0.72
Braidwood	69010	0.50	0.70	0.93	0.99	0.76
Crookwell	70025	0.53	0.68	0.94	0.99	0.78
Nimmitabel	70067	0.38	0.67	0.95	0.99	0.75
Yass	70091	0.67	0.71	0.93	0.98	0.78
Tumbarumba	72043	0.62	0.66	0.93	0.99	0.76
Tumut	72046	0.67	0.68	0.95	1.00	0.82
Binalong	73005	0.68	0.70	0.94	0.99	0.72
Cootamundra	73009	0.78	0.74	0.93	0.98	0.80
Grenfell	73014	0.79	0.76	0.93	0.97	0.77
Young	73056	0.73	0.69	0.92	0.98	0.82
Gundagai	73128	0.79	0.77	0.94	0.99	0.72
Lockhart	74064	0.77	0.70	0.95	0.98	0.75
Tocumwal	74106	0.75	0.67	0.92	0.97	0.83
Echuca	80015	0.79	0.68	0.93	0.96	0.85
			Fescue			
Gilgandra	51018	0.67	0.55	0.89	0.97	0.84
Barraba	54003	0.49	0.64	0.92	0.99	0.69
Manilla	55031	0.63	0.60	0.89	0.97	0.78
Quirindi	55049	0.59	0.61	0.92	0.99	0.72
Inverell	56017	0.51	0.69	0.92	0.99	0.69
Scone	61089	0.72	0.68	0.93	0.99	0.80
Singleton	61275	0.56	0.52	0.90	0.99	0.82
Mudgee	62021	0.61	0.69	0.92	0.99	0.81
Coonabarabra n	64008	0.61	0.71	0.94	0.99	0.76
Dunedoo	64009	0.64	0.66	0.92	0.98	0.78
			Annual			
Condobolin	50052	0.66	0.74	0.92	0.97	0.73
Dubbo	65012	0.69	0.77	0.91	0.97	0.78
Forbes	65016	0.72	0.77	0.90	0.97	0.78
Parkes	65026	0.67	0.78	0.92	0.97	0.75
Temora	73038	0.72	0.78	0.94	0.98	0.85
Wyalong	73054	0.68	0.69	0.86	0.95	0.81
Coolamon	74033	0.71	0.76	0.90	0.97	0.86

Table 8c. Stage 4 correlation co-efficient (R^2) between GrassGro and calibrated GRASP simulations for soil moisture (0-50cm) and pasture variables; green and total standing dry matter, accumulated monthly pasture growth and animal intake (set to zero 1 Feb each year).

Location	BoM station No.	Green SDM	Total SDM	Accumulated growth	Accumulated intake	Soil water
			Phalaris optimisation set			
Bathurst	63005	0.55	0.68	0.91	0.96	0.71
Wellington	65035	0.67	0.66	0.91	0.98	0.69
Bega	69002	0.42	0.45	0.82	0.96	0.74
Goulburn	70263	0.66	0.73	0.94	0.99	0.74
Cooma	70278	0.34	0.57	0.92	0.98	0.68
Albury	72146	0.84	0.75	0.95	0.99	0.84
			Phalaris validation set			
Cowra	63023	0.70	0.70	0.92	0.97	0.71
Lithgow	63224	0.41	0.58	0.93	1.00	0.75
Orange	63231	0.57	0.69	0.94	0.99	0.84
Moss Vale	68045	0.47	0.65	0.96	1.00	0.71
Braidwood	69010	0.50	0.67	0.93	0.99	0.75
Crookwell	70025	0.54	0.68	0.94	0.99	0.76
Nimmitabel	70067	0.39	0.67	0.94	0.99	0.74
Yass	70091	0.67	0.71	0.93	0.98	0.76
Tumbarumba	72043	0.62	0.64	0.93	0.99	0.76
Tumut	72046	0.71	0.68	0.95	1.00	0.82
Binalong	73005	0.69	0.70	0.94	0.99	0.71
Cootamundra	73009	0.77	0.72	0.93	0.97	0.79
Grenfell	73014	0.79	0.76	0.93	0.97	0.76
Young	73056	0.73	0.70	0.93	0.98	0.81
Gundagai	73128	0.80	0.75	0.94	0.99	0.73
Lockhart	74064	0.78	0.72	0.95	0.98	0.75
Tocumwal	74106	0.75	0.66	0.91	0.97	0.82
Echuca	80015	0.80	0.67	0.93	0.96	0.82
			Fescue			
Gilgandra	51018	0.67	0.56	0.89	0.96	0.84
Barraba	54003	0.47	0.63	0.92	0.99	0.69
Manilla	55031	0.63	0.61	0.89	0.97	0.77
Quirindi	55049	0.58	0.63	0.92	0.99	0.71
Inverell	56017	0.50	0.70	0.91	0.99	0.69
Scone	61089	0.71	0.67	0.93	0.99	0.80
Singleton	61275	0.56	0.51	0.90	0.99	0.82
Mudgee	62021	0.60	0.69	0.92	0.99	0.81
Coonabarabran	64008	0.58	0.71	0.93	0.99	0.76
Dunedoo	64009	0.62	0.65	0.92	0.98	0.79
			Annual			
Condobolin	50052	0.72	0.78	0.93	0.97	0.72
Dubbo	65012	0.74	0.79	0.90	0.97	0.77
Forbes	65016	0.75	0.79	0.89	0.96	0.78
Parkes	65026	0.73	0.83	0.91	0.97	0.76
Temora	73038	0.77	0.82	0.93	0.99	0.84
Wyalong	73054	0.73	0.68	0.85	0.95	0.80
Coolamon	74033	0.76	0.79	0.90	0.97	0.85

Table 8d. Stage 5 correlation co-efficient (R^2) between GrassGro and calibrated GRASP simulations for soil moisture (0-50cm) and pasture variables; green and total standing dry matter, accumulated monthly pasture growth and animal intake (set to zero 1 Feb each year).

Location	BoM station No.	Green SDM	Total SDM	Accumulated growth	Accumulated intake	Soil water
			Phalaris optimisation set			
Bathurst	63005	0.64	0.72	0.91	0.96	0.70
Wellington	65035	0.75	0.69	0.91	0.98	0.70
Bega	69002	0.49	0.50	0.82	0.97	0.72
Goulburn	70263	0.68	0.73	0.93	0.99	0.71
Cooma	70278	0.41	0.62	0.92	0.98	0.67
Albury	72146	0.87	0.75	0.95	0.99	0.83
			Phalaris validation set			
Cowra	63023	0.72	0.69	0.91	0.97	0.70
Lithgow	63224	0.49	0.62	0.93	1.00	0.75
Orange	63231	0.64	0.73	0.95	0.99	0.84
Moss Vale	68045	0.52	0.67	0.93	1.00	0.69
Braidwood	69010	0.56	0.70	0.92	0.99	0.72
Crookwell	70025	0.57	0.69	0.94	1.00	0.75
Nimmitabel	70067	0.45	0.74	0.95	0.99	0.74
Yass	70091	0.71	0.72	0.92	0.98	0.73
Tumbarumba	72043	0.65	0.65	0.93	0.99	0.76
Tumut	72046	0.68	0.66	0.94	1.00	0.80
Binalong	73005	0.67	0.70	0.93	0.99	0.68
Cootamundra	73009	0.80	0.71	0.92	0.97	0.78
Grenfell	73014	0.76	0.72	0.91	0.97	0.74
Young	73056	0.75	0.68	0.91	0.98	0.79
Gundagai	73128	0.80	0.74	0.93	0.99	0.74
Lockhart	74064	0.80	0.71	0.94	0.98	0.73
Tocumwal	74106	0.78	0.65	0.90	0.97	0.79
Echuca	80015	0.81	0.63	0.91	0.96	0.80
			Fescue			
Gilgandra	51018	0.79	0.65	0.90	0.95	0.82
Barraba	54003	0.64	0.65	0.92	0.98	0.73
Manilla	55031	0.69	0.59	0.88	0.96	0.75
Quirindi	55049	0.64	0.64	0.93	0.99	0.69
Inverell	56017	0.64	0.71	0.92	0.99	0.76
Scone	61089	0.74	0.71	0.92	0.98	0.76
Singleton	61275	0.57	0.54	0.89	0.98	0.77
Mudgee	62021	0.74	0.76	0.93	0.98	0.82
Coonabarabran	64008	0.73	0.77	0.94	0.99	0.77
Dunedoo	64009	0.77	0.76	0.93	0.98	0.79
			Annual			
Condobolin	50052	0.73	0.79	0.93	0.97	0.69
Dubbo	65012	0.72	0.77	0.90	0.97	0.74
Forbes	65016	0.75	0.77	0.90	0.96	0.75
Parkes	65026	0.70	0.78	0.91	0.97	0.73
Temora	73038	0.77	0.83	0.93	0.99	0.81
Wyalong	73054	0.72	0.73	0.86	0.95	0.78
Coolamon	74033	0.74	0.77	0.90	0.96	0.82

Figure 14a. Comparison of correlation co-efficients (R^2) between Stages 2 and 3 of the calibration procedure (Table 7) for 41 locations. Stage 2 - all parameters calibrated but with tight bounds. Stage 3 - all 22 parameters calibrated with tight bounds but pasture standing dry matters and accumulated pasture growths greater than10,000 kg DM/ha were excluded from the objective function in PEST.

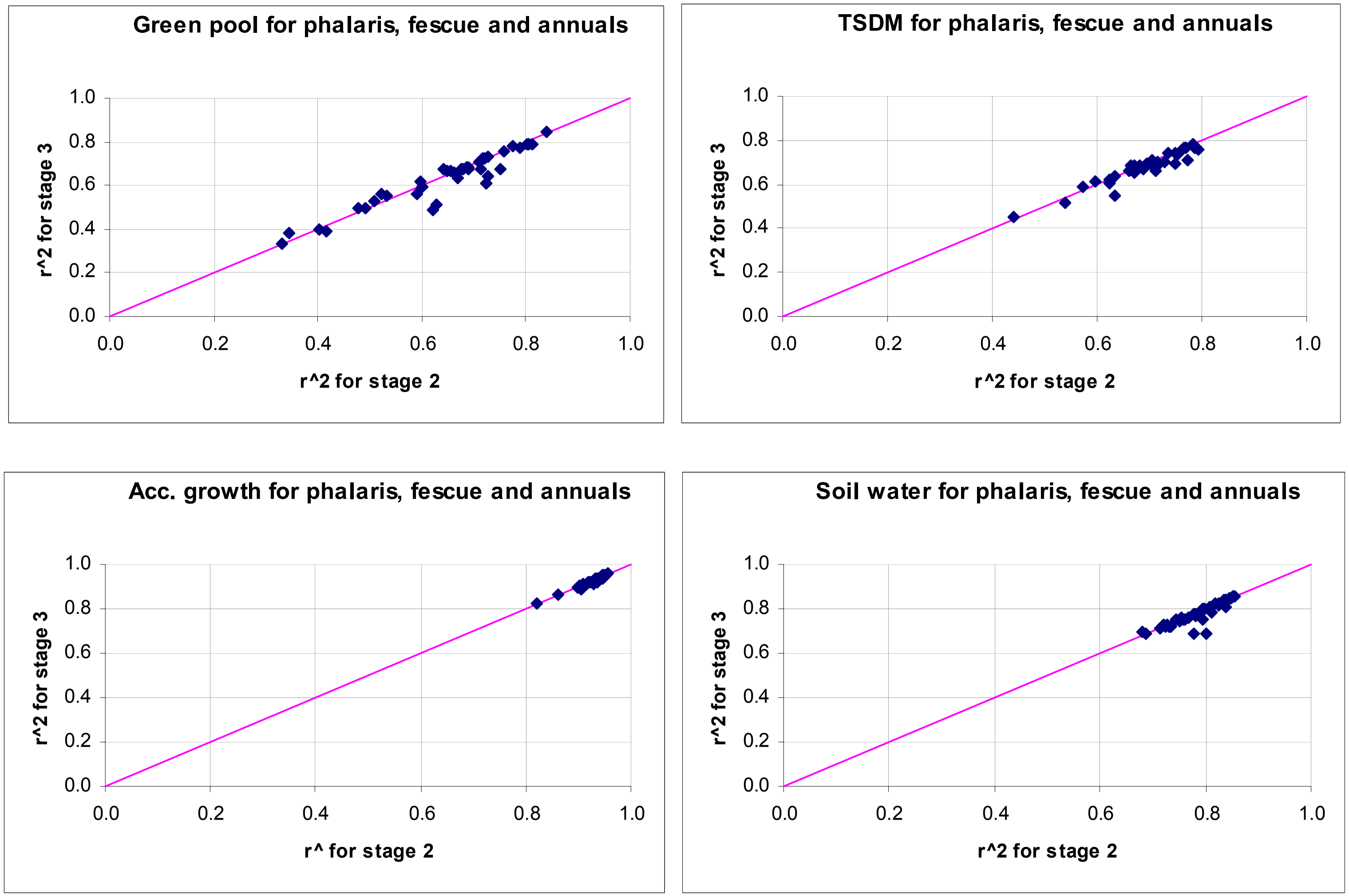


Figure 14b. Comparison of correlation co-efficients (R^2) between Stages 2 and 4 of the calibration procedure (Table 7) for 41 locations. Stage 2 - all parameters calibrated but with tight bounds. Stage 4 – 25 parameters calibrated with increased bounds on selected parameters; inclusion of litter pools; soil evaporation parameters; and high yield and growth values excluded from objective function.

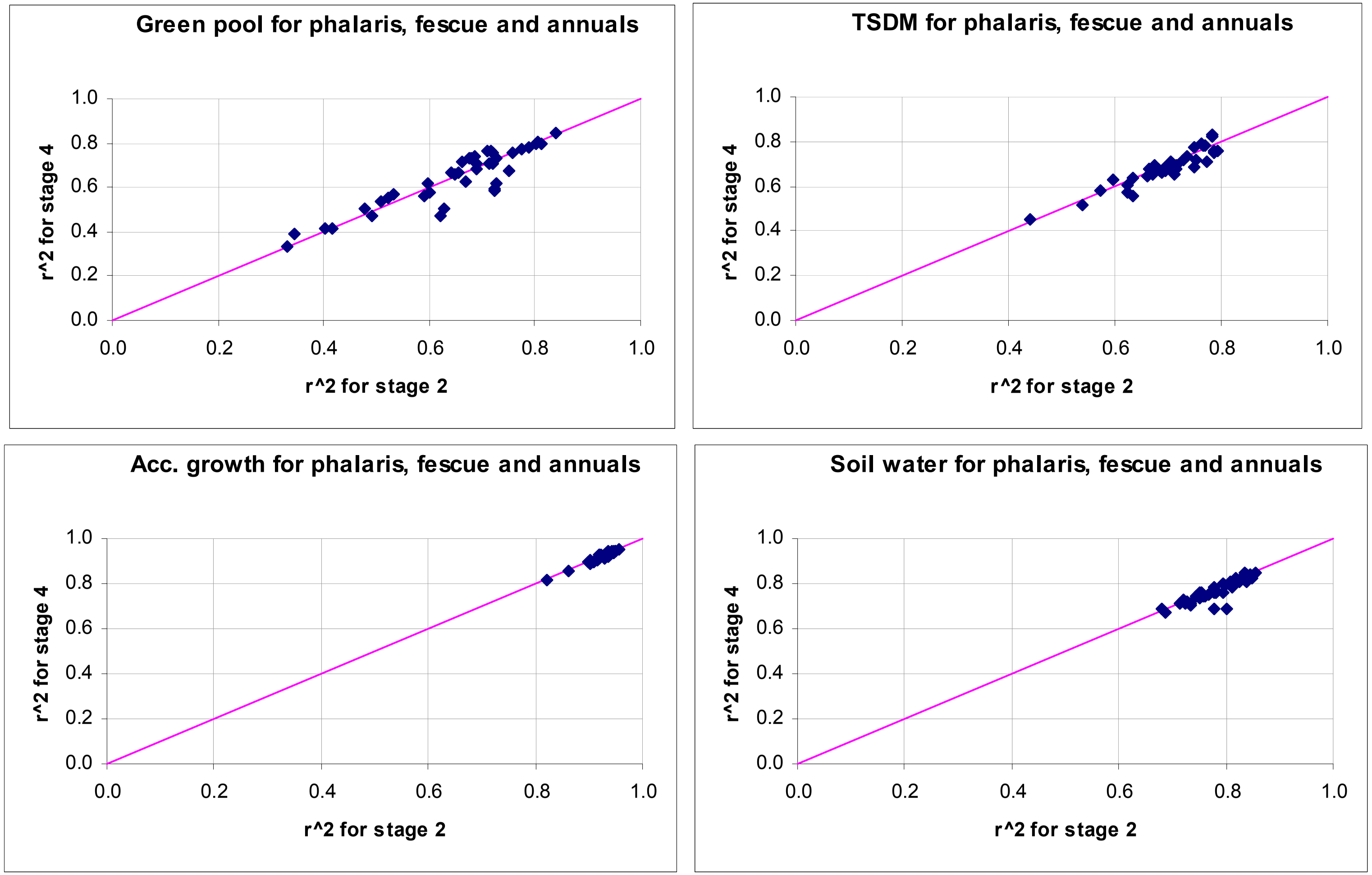


Figure 14c. Comparison of correlation co-efficients (R^2) between Stages 2 and 5 of the calibration procedure (Table 7) for 41 locations. Stage 2 - all parameters calibrated but with tight bounds. Stage 5 – further development of Stage 4 with increased bounds on selected parameters; inclusion of litter pools; soil evaporation parameters; and fewer parameters calibrated (19).

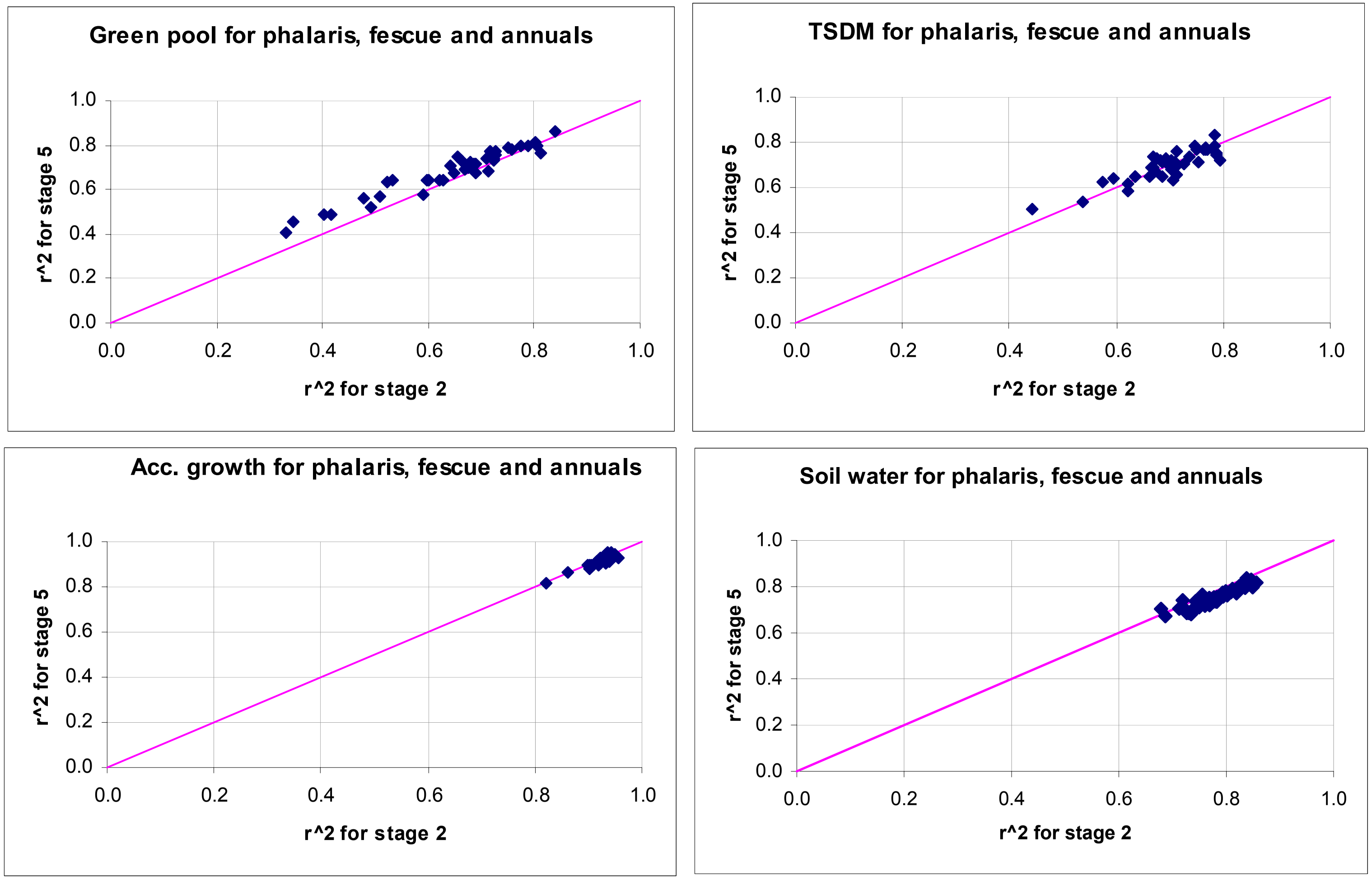


Figure 15. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

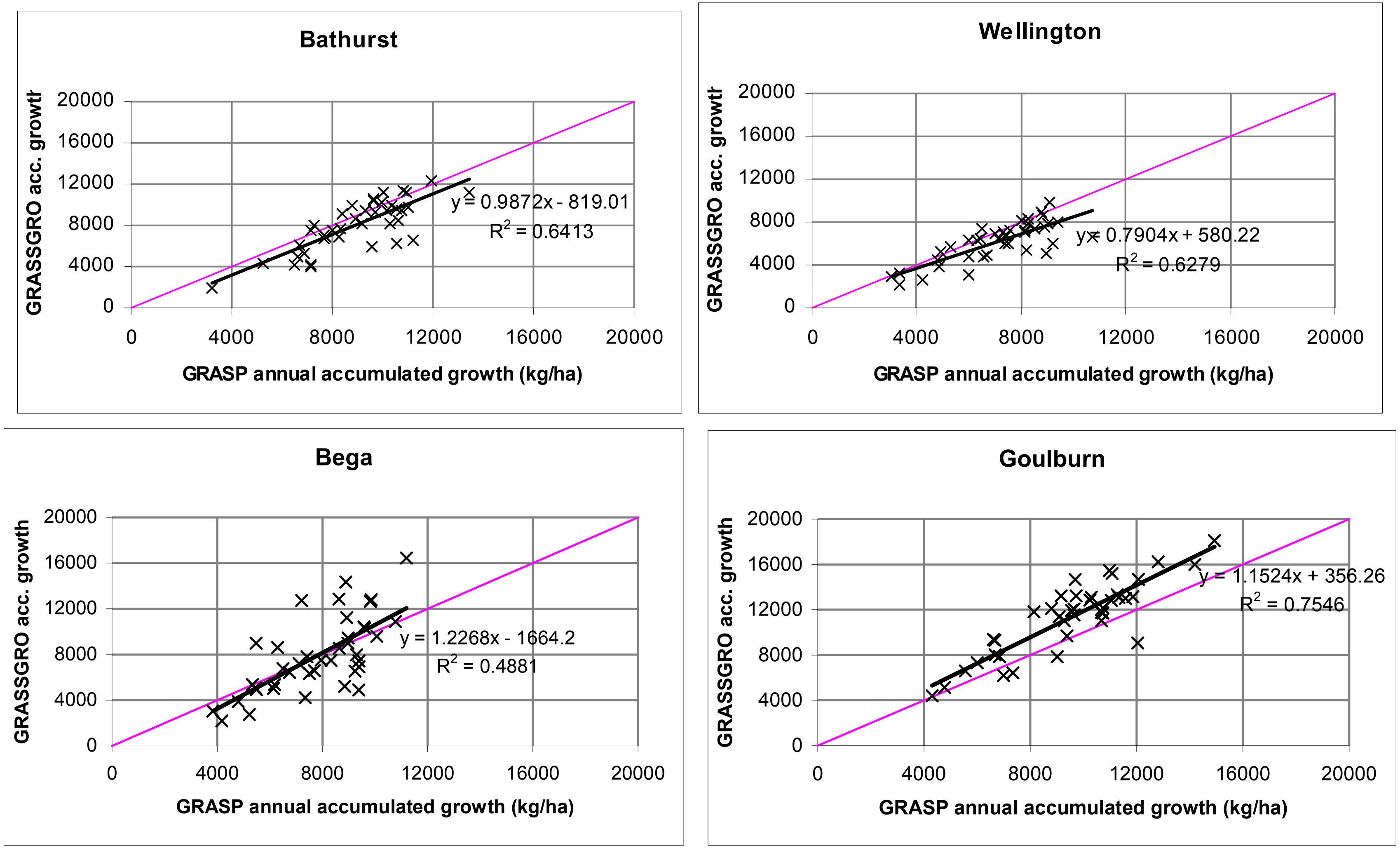


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

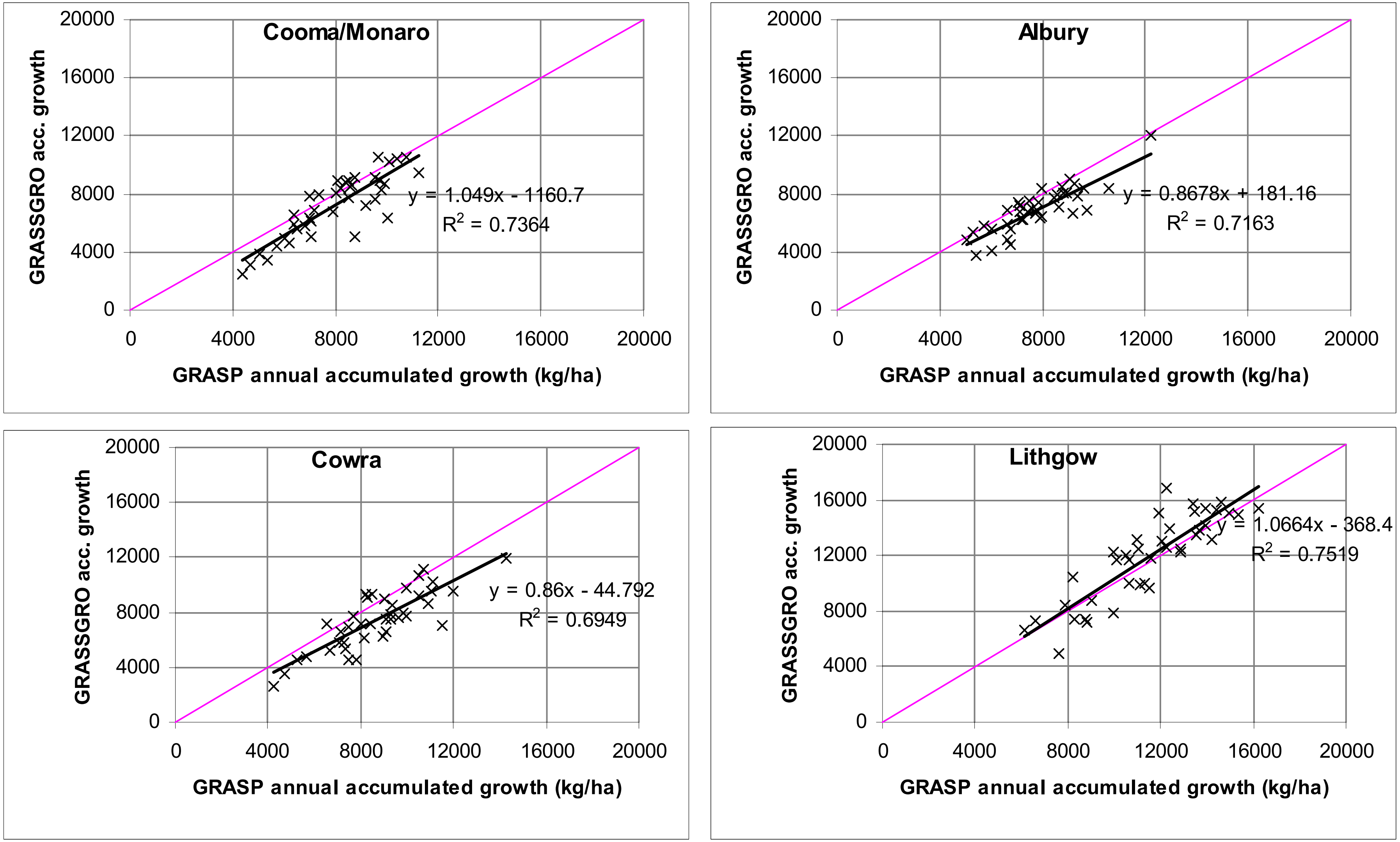
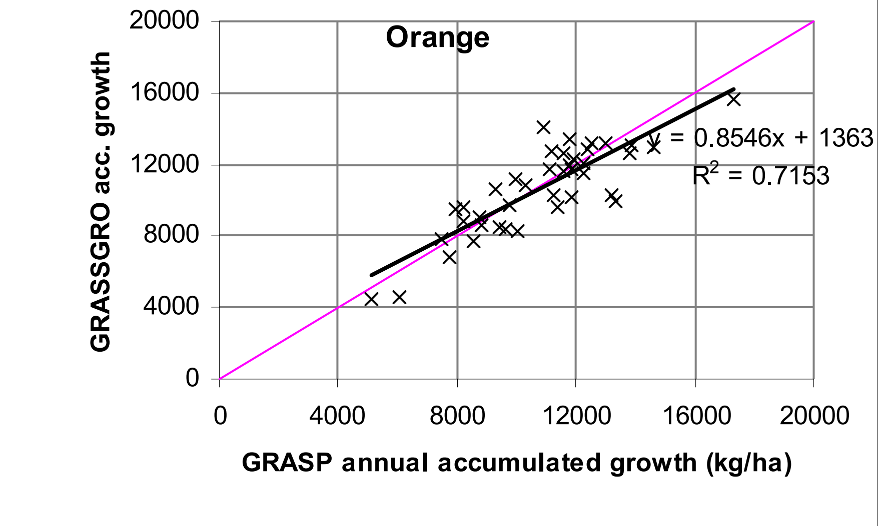
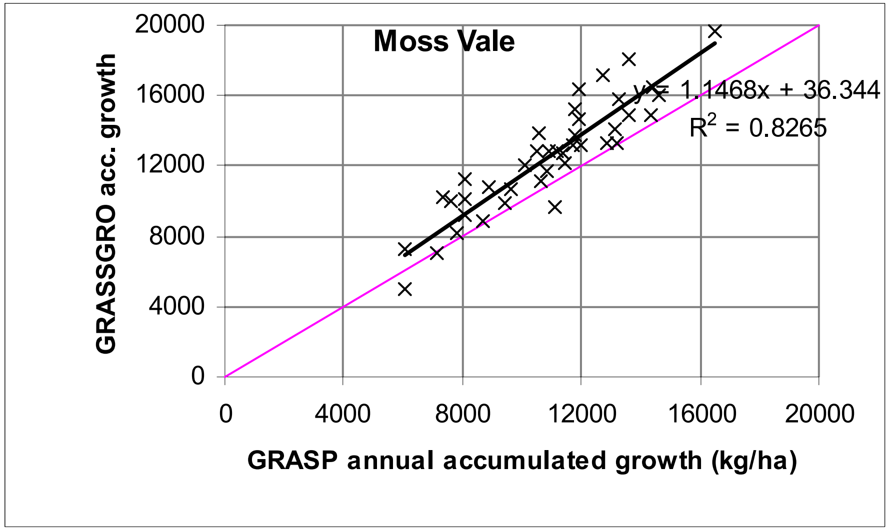
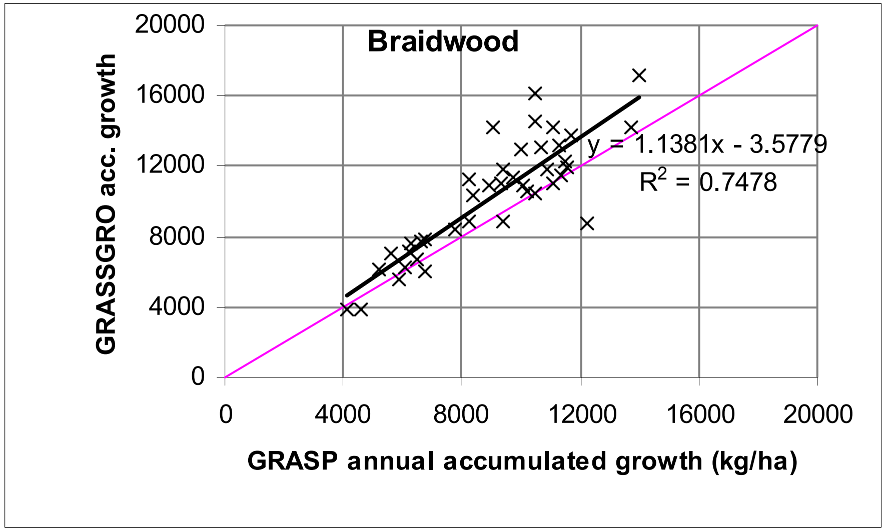


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.







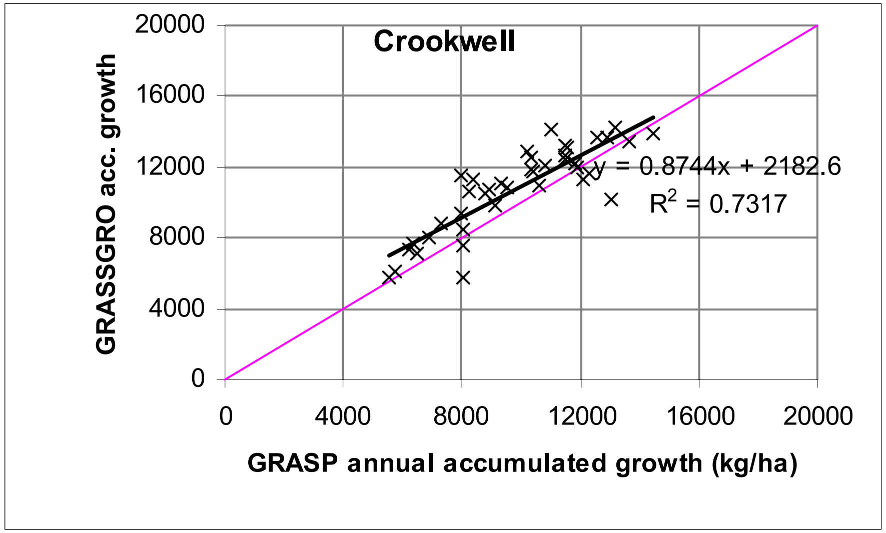


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

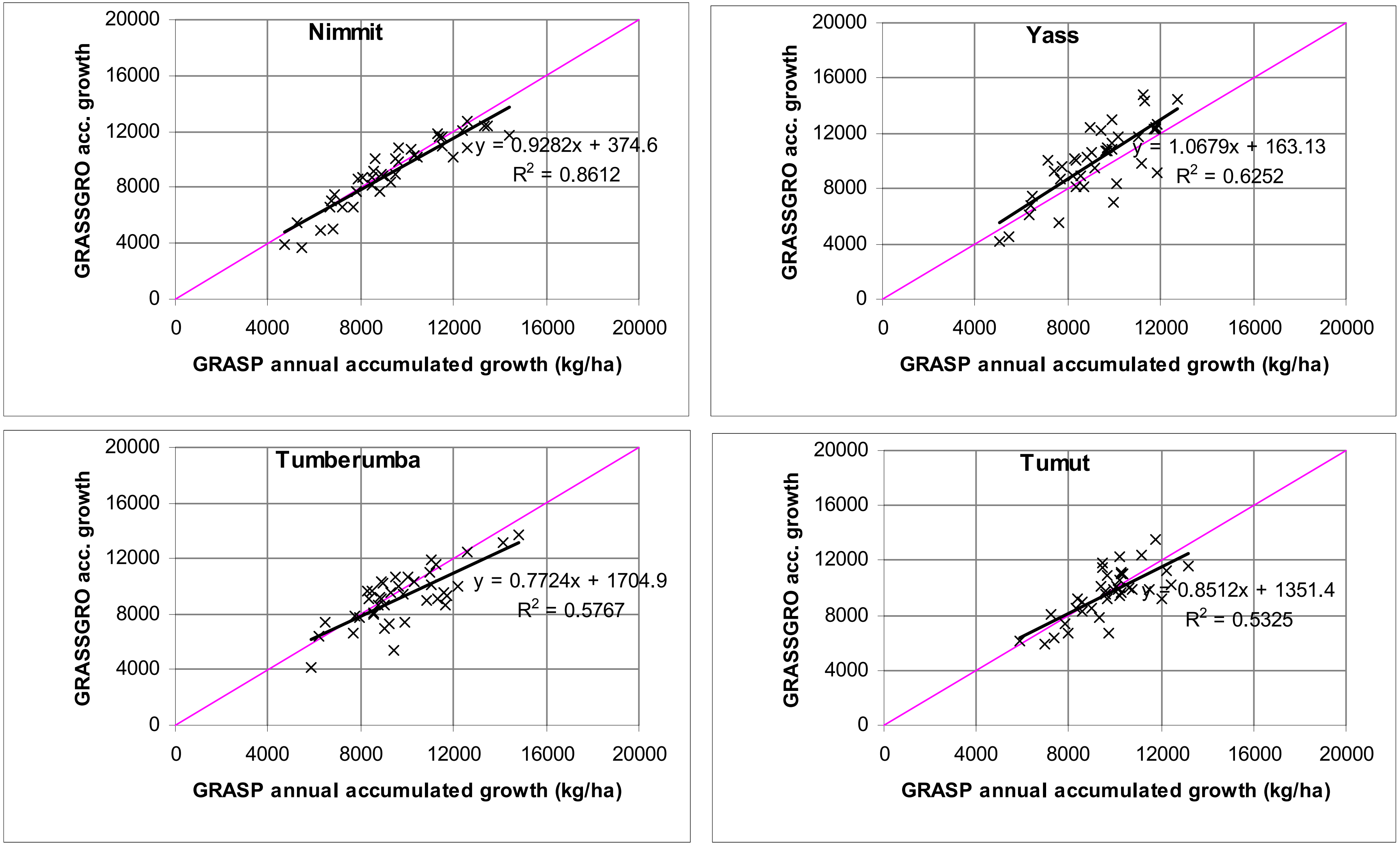


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

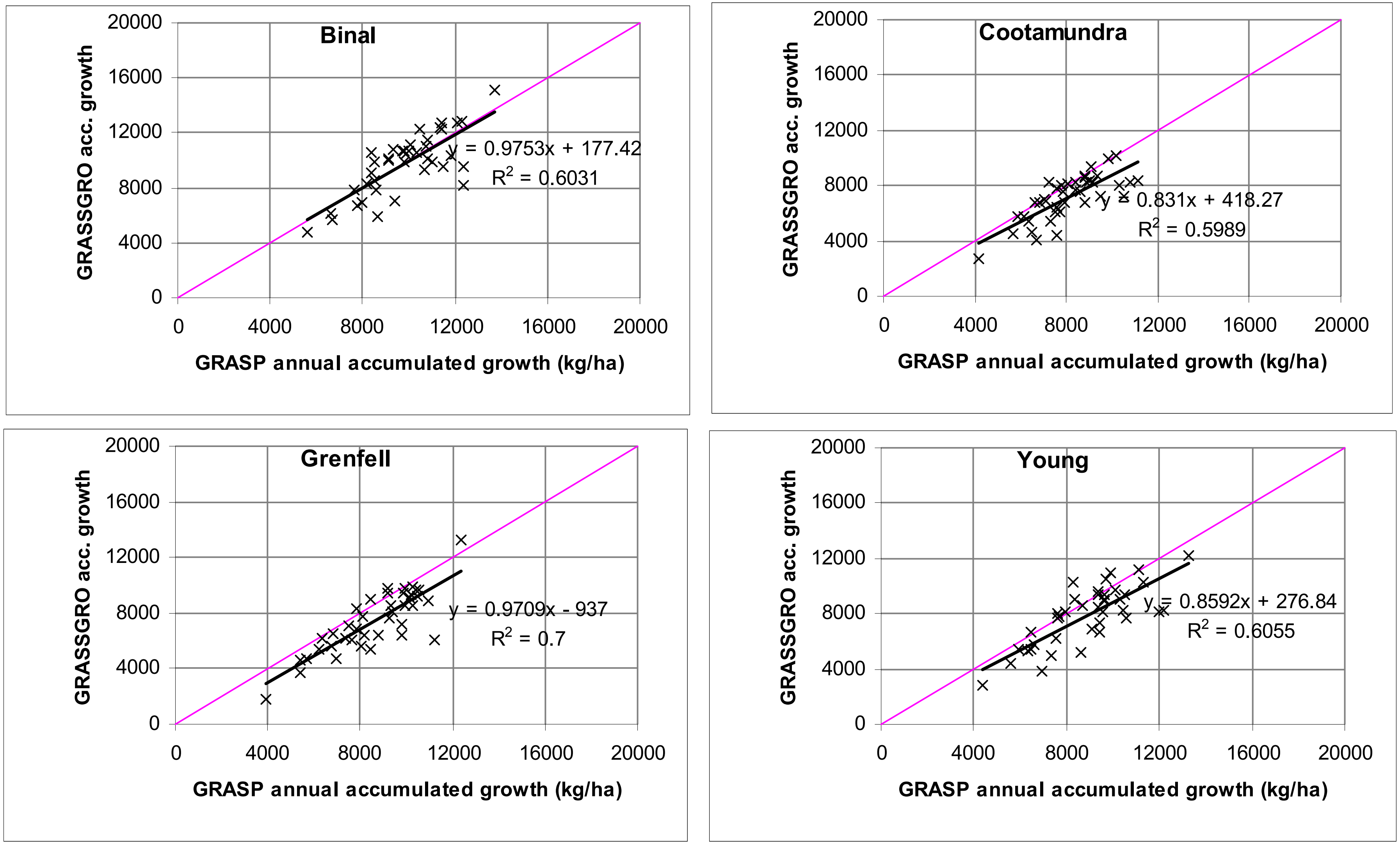


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

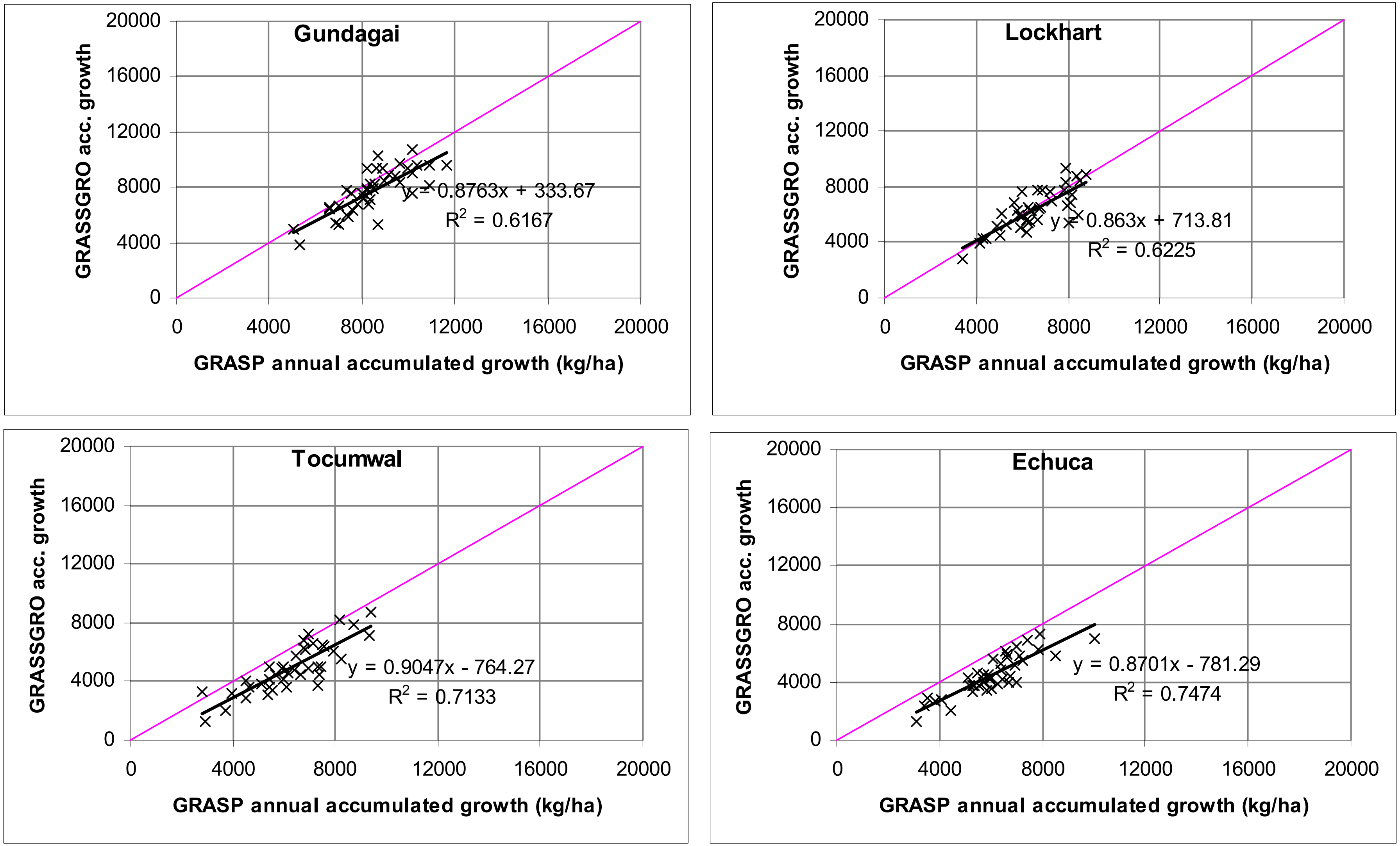


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

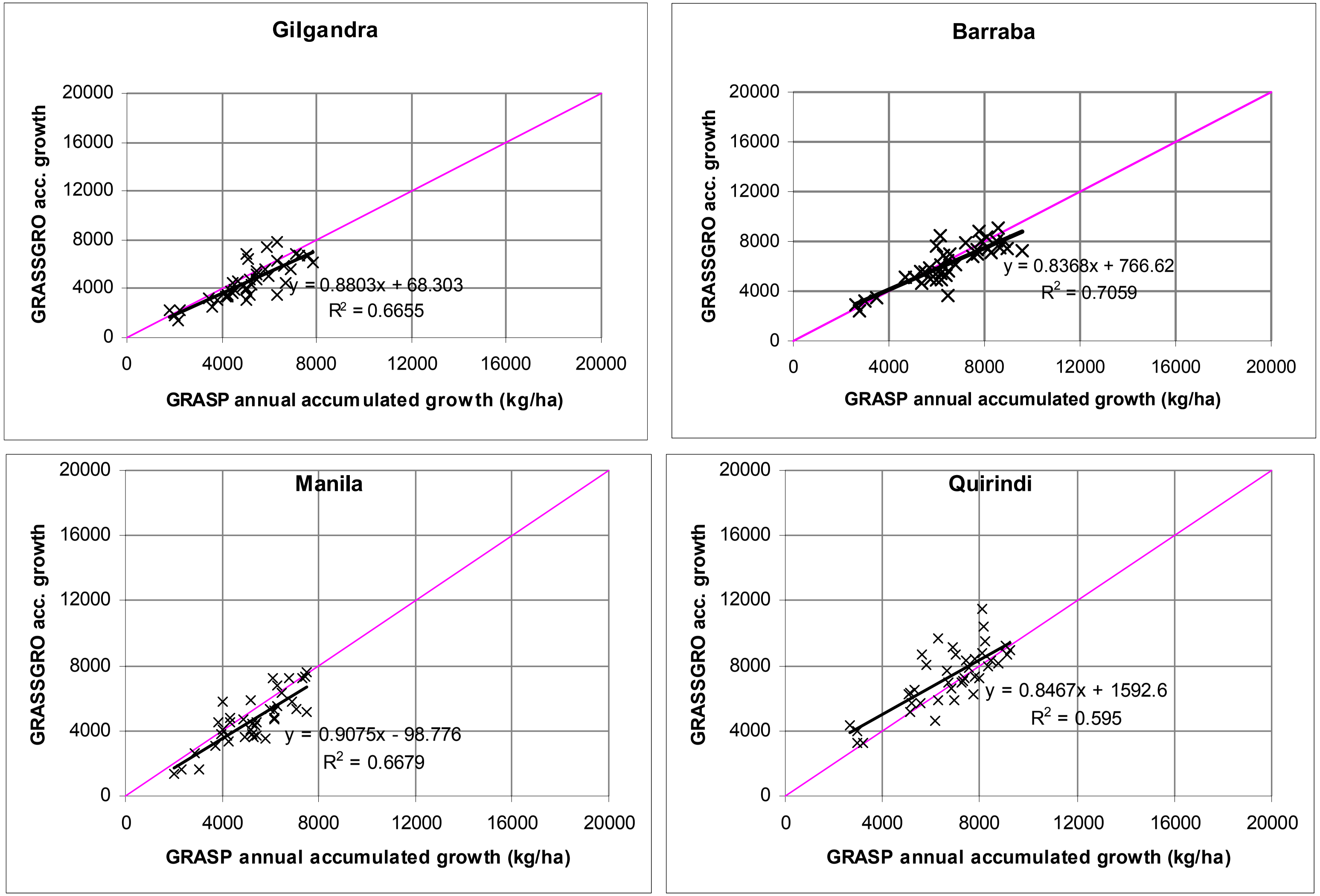


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

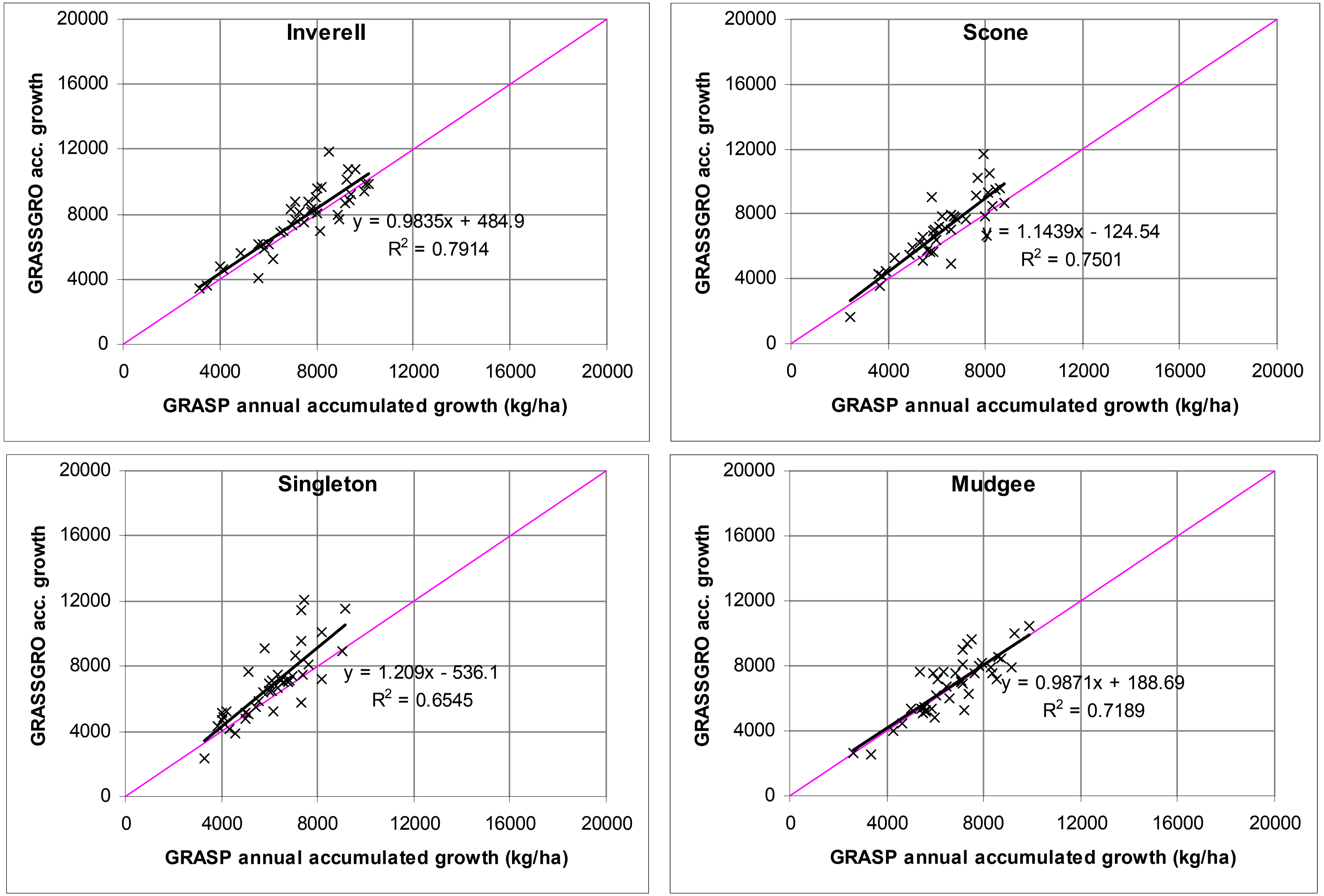


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

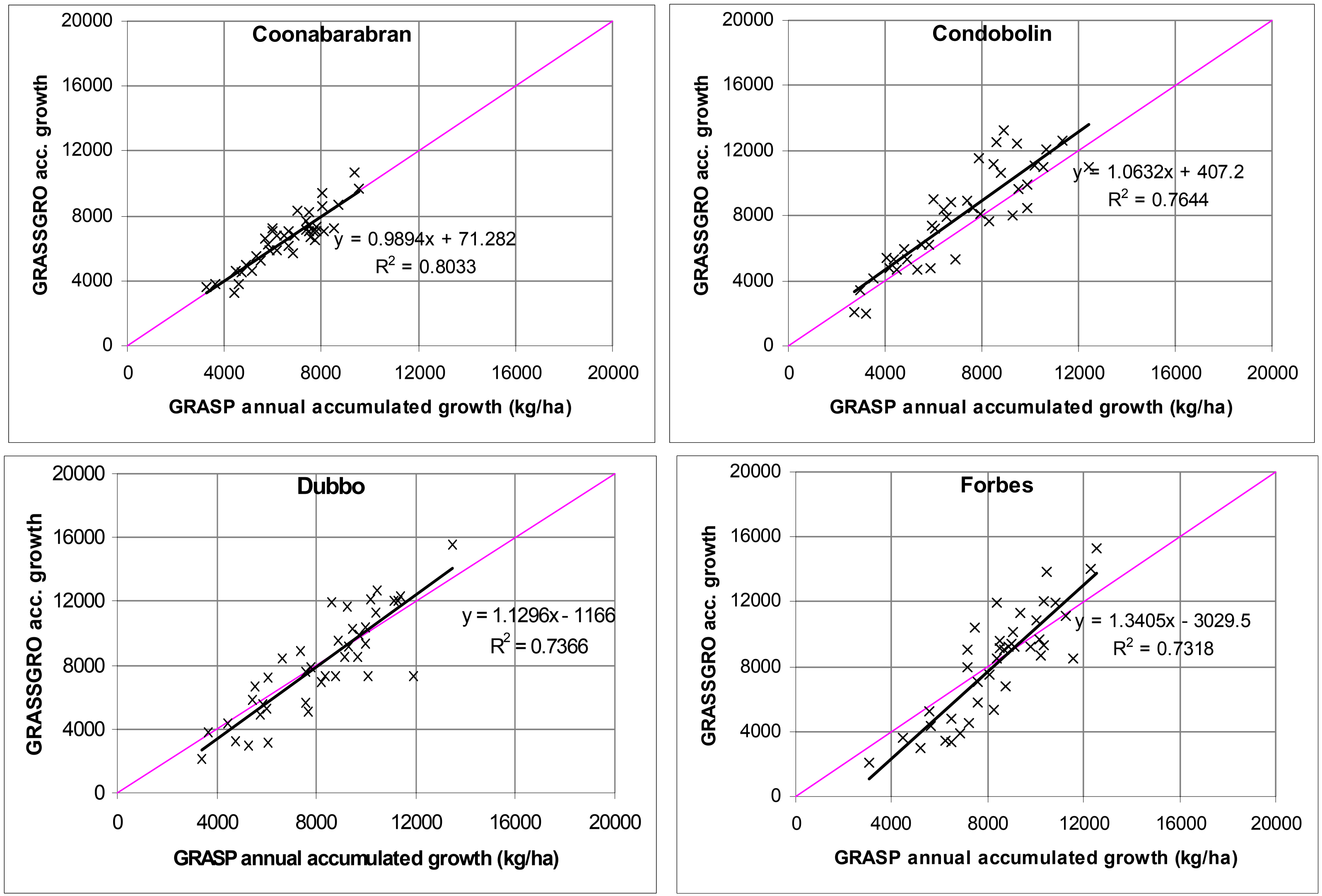


Figure 15 continued. Comparison of simulated annual growth for 41 locations for years 1960 to 1999 – Stage 2 of calibration.

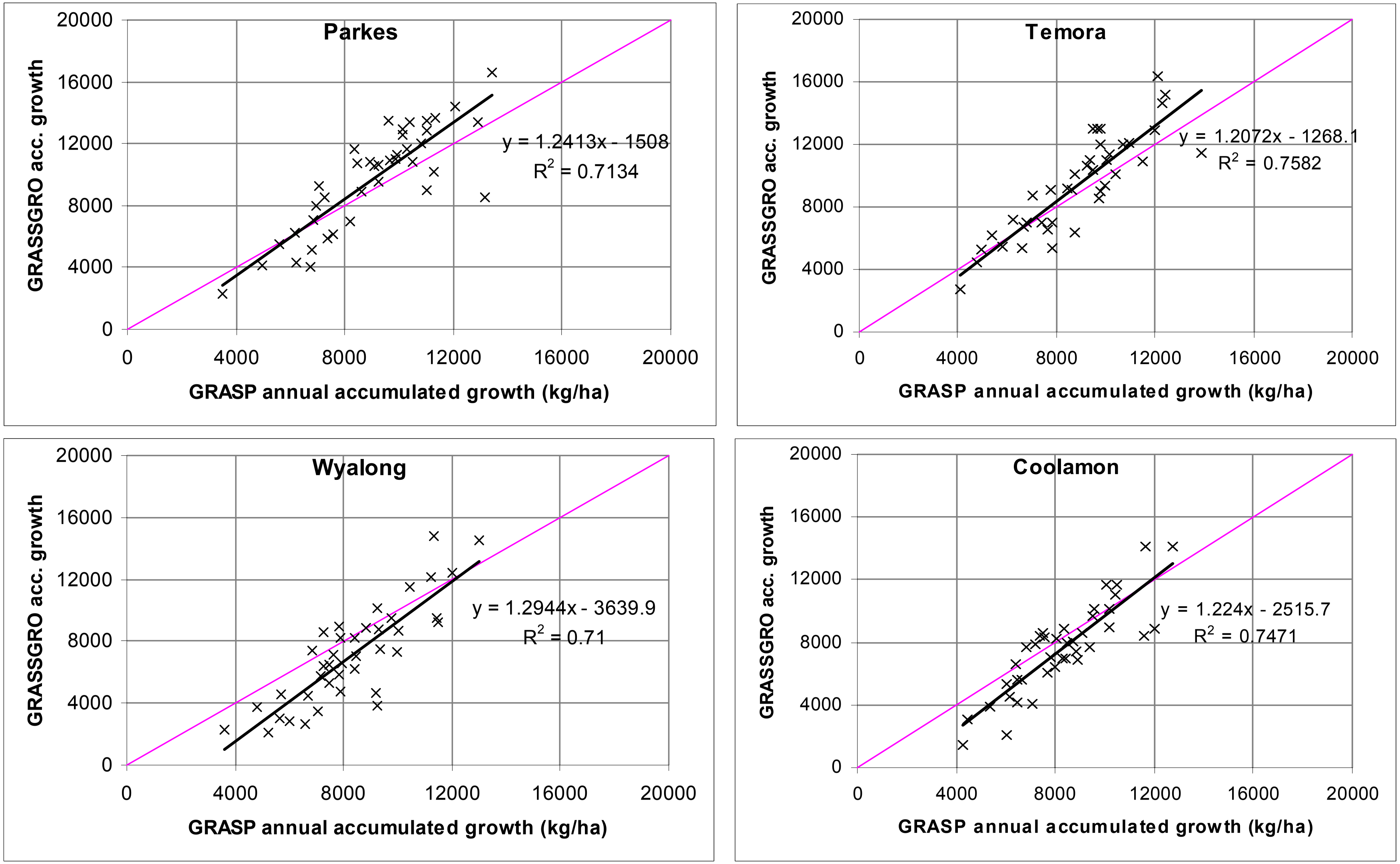


Table 9. Correlation co-efficients (R^2) and regression equations for annual growth (1 Feb to 31 Jan) for each species group of locations: GRASP (x) and GrassGro (y). Annual growth values are for years 1960 to 1999 inclusive. In calibration Stage 3, accumulated annual growth and pasture standing dry matter yield greater than 10,000 kg/ha were excluded from the calibration objective function but values were retained for the comparison reported below. X:Y plots for individual locations are shown in Figure 15.

Group	Calibration stage	R^2	Regression
Phalaris - six locations	2	0.644	– 1548 + 1.158x
	3	0.635	– 1835 + 1.228x
Phalaris validation set - 18 locations	2	0.762	- 1207 + 1.108x
	3	0.764	- 1472 + 1.172x
Fescue - 10 locations	2	0.721	– 130 + 1.038x
	3	0.722	– 728 + 1.118x
Annual ryegrass - 7 locations	2	0.703	– 1532 + 1.184x
	3	0.702	– 1592 + 1.233x

In contrast the low values of annual growth occurring in drought years or at drier locations were overestimated by the calibrated GRASP parameter set (Table 9). Removing values above 10,000 kg/ha in the calibration procedure did not reduce this bias.

For the fescue group there was a similar lack of agreement in the extremely high growth year/location combinations but better agreement under low growth conditions (Table 9 and Figure 15). For the annual ryegrass group there was a similar bias as found in the phalaris group. The GrassGro simulations are likely to be redone, because of the uncertainty of the high growths simulated here, and as a result we have not pursued the investigation of achieving better agreement under dry conditions with the current data set.

7.6.2 Soil moisture

Soil moisture (0-50cm was well simulated at most locations (R^2 from .68 to .86) with 31 of the 41 locations having ($R^2 > 0.75$). Inspection of individual locations indicated a common type of error in which GRASP values were near constant at the upper limit whilst GrassGro values showed much larger variation (e.g. Cooma). This pattern of error was not unexpected given that GrassGro simulated soil moisture above field capacity at some locations for a relatively high proportion of the time (Table 4).

7.6.3 Animal intake

As annual stocking rates (Table 3) were derived from the GrassGro output simulated intakes were in good agreement. However the variation in the parameter restricting intake (p144) for the 3 species groups was surprising and requires further investigation.

7.6.4 Green pasture pools

For the six phalaris locations there was considerable variation in the agreement between GrassGro and GRASP simulations with R^2 ranging from 0.33 at Cooma to 0.84 at Albury. A similar range occurred in the phalaris validation data (0.35 at Nimmitabel to 0.81 at Grenfell and Gundagai). Agreement appeared to be higher in the more western area of the phalaris set (BoM districts 73, 74 and 80).

For the fescue and annual ryegrass sets, agreement was more consistent across locations with R^2 ranging from 0.60 to 0.75.

Inspection of individual locations showed that, as with pasture growth, the wet early 1960s were a major source of error at some locations (Bega, Goulbourn (phalaris), Singleton (fescue), Condobolin (annual ryegrass)).

The lack of agreement in simulating green pasture dry matter is a source of concern since:

1. 'green' was given the highest weighting in the calibration procedure (Table 6); and
2. green DM pool has major effects on growth and water use in GRASP.

However, inspection of individual locations suggests that some of the lack of agreement relates to the timing of rapid onset of senescence and hence does not greatly affect the simulation of plant growth.

7.6.5 Total standing dry matter

For the phalaris locations, pasture standing dry matter was generally in closer agreement where the green component was not well simulated (e.g. Cooma, Bathurst, Nimmitabel). For fescue and annual ryegrass sets agreement was similar to R^2 for the green pool. Overall 21 locations had $R^2 > 0.70$. In the independent phalaris data set only one of the 18 locations had a R^2 less than 0.65 providing independent validation of the calibrated parameters. Inspection of individual locations indicates good agreement at low TSDM values (< 2000 kg/ha) with major errors in wet early 1960s at some locations.

7.6.6 Summary of findings of Stages 2 and 3

Given that both models include similar biological and hydrological processes with strong effects of daily climate variation it was expected that GRASP parameters could be calibrated to simulate a high proportion of the temporal and spatial variation simulated by GrassGro. The detailed review of the two models indicated substantial differences in the detail of individual processes and the calibration procedure described above indicated that 60-70% of the temporal and spatial variation in annual pasture growth and SDM simulated by GrassGro could be represented by GRASP. The judgement as to whether this is adequate depends on the applications of GRASP in the context of Aussie GRASS.

7.6.6.1 Independent validation

A particularly encouraging finding in Stages 2 and 3 was the independent validation of the calibrated parameter sets for phalaris. For the 18 independent locations agreement with pasture growth, soil moisture and dry matter pools was equal to that achieved for the six sites used in calibration (Tables 7, 8). This result suggests that the calibration procedure is reasonably robust and that the parameters derived using all fescue and annual ryegrass locations are likely to be equally robust.

7.6.7 Summary of findings of Stages 4 and 5

In Stages 2 and 3 the calibrated values for several parameters were at the upper or lower bounds. Of particular importance was parameter P045 'the green yield at potential transpiration is 50% of Class A pan'. The higher calibrated values for P045, compared to Stage 1, suggested that evapotranspiration may have been over-estimated in preliminary simulations in Stage 1 (April 2000). The inclusion of soil moisture data with new simulations of pasture variables is the most likely cause of the high values calibrated for P045. P045 and P009 ('soil moisture index for maximum green cover') interact in the calculation of the effect of water stress on green cover. Sensible values were found for P009 suggesting that the high values for P045 were not a compensation for non-sensible values of P009.

As indicated in the review above, the models differ in formulation of evapotranspiration. To test the effect on calibration, the soil evaporation parameter P033 ('daily maximum for soil evaporation') and litter decomposition variables were included in Stage 4. The upper bounds of P045 was increased to 3,000. The calibrated parameter set did not substantially improve (as measured by R^2) simulation of pasture and soil moisture variables (Figure 14b).

In Stage 5 a number of parameters were fixed to sensible values to improve efficiency of calibration (19 parameters) and bounds on parameters P045 and temperature response were changed. Whilst improvement in simulation of green material occurred, better agreement with other important variables such as annual pasture growth did not occur.

7.6.8 Application example: variability in pasture growth

Annual pasture growths simulated by GrassGro for the 41 locations and 40 years (1960 to 1999) were compared with a range of variables simulated by GRASP. Correlations for each group of locations showed that, as expected, 'GrassGro – annual' growth is not well correlated with input annual rainfall (Table 10) confirming that the GrassGro model provides a substantial transformation on how seasonal and spatial rainfall distribution affects plant growth. Similarly low correlations between annual rainfall and pasture growth have been measured in exclosures for Queensland native pastures (Day *et al.* 1997). Simulated variables 'annual growth index', 'annual transpiration' and 'pasture growth' accounted for 60-70% of variation (Table 10) in GrassGro - annual growth suggesting that GRASP captures the similar dominating effect of variation in temporal and spatial rainfall distribution. Thus, despite the differences in models the overriding effects of rainfall variability are reasonably well represented.

A major use of Aussie GRASS has been the analysis of year-to-year variation in annual growth with particular attention to drought years (Day 1998, 1999, Carter *et al.* 2000). Figure 15 shows the comparison between GrassGro and GRASP annual growth for each location. Generally there is agreement in ranking of lowest year or years. Important exceptions are Lithgow, Crookwell, Tocumwal, Cootamundra, Dubbo, Wyalong. In these six cases discrimination in the lowest years is not as evident as at the other locations.

Table 10. Correlation co-efficients (R^2) of climate and simulated variables with GrassGro annual growth (1 Feb to 31 Jan) for individual years from 1960 to 1999 for different species groups. Accumulated annual growth index, transpiration and growth were simulated by GRASP using parameter sets calibrated in Stage 2.

Group	Annual rainfall	Accumulated annual Growth Index	Accumulated annual transpiration	Simulated annual growth
Phalaris - 6 locations	0.183	0.561	0.537	0.643
Phalaris validation set 18 locations	0.488	0.715	0.702	0.761
Fescue - 10 locations	0.376	0.604	0.709	0.721
Annual ryegrass - 7 locations	0.398	0.669	0.705	0.701

In the case of the highest years there were more locations in which there was little discrimination (e.g. Bega, Lithgow, Yass, Tumut, Cootamundra, Grenfell, Lockhart, Gilgandra, Quirindi, Singleton, Scone, Condobolin).

Table 11 shows the correlations (R^2) between annual growth and '8 month' growth (Feb to Sept) for each location for two stages of calibration (Stage 2 and 5). For Stage 2 calibration 25 of the 41 locations R^2 were greater than 0.70. Half (9) of the 18 locations in the independent data had R^2 greater than 0.70. Only four locations had R^2 less than 0.60 (Bega, Tumbarumba, Tumut and Quirindi). Correlations for accumulated growth for the eight months (1 Feb to 30 Sept) were generally not as high as for the 12-month period (1 Feb to 31 Jan) and hence spring/summer is not necessarily the major source of disagreement between the models in terms of year-to-year variability.

7.7 Conclusion

The results show that for most locations 60-70% of the temporal and spatial variation simulated by GrassGro could be represented by GRASP with sensible calibrated parameter sets. The parameter set for phalaris was also independently validated on a 'data' set not used in the calibration. In environments with greater year-to-year variation pasture growth (i.e. rangelands and tropical nature pastures) independent tests indicate that GRASP accounts for 60-70% of temporal and spatial variability (Day *et al.* 1997). Although sampling error is often a major source of error in field measurements, there are also known physical and biological processes not yet included in GRASP (McKeon *et al.* 2000) which are likely to be contributing to unexplained variation.

The GrassGro simulations represent a different type of 'data' to field data in that there is no sampling variability and all processes that contribute to variation are 'known', i.e. defined by the model. Thus our inability to parameterise GRASP to represent 100% of simulated variation can be attributed to different model formulation and processes.

The judgement of whether the calibration version of GRASP is adequate depends on (1) whether the differences are real, i.e. can be observed and measured in the field; and (2) whether the differences have major impacts on the application of the models. An example application was evaluated above and the models were similar in ranking dry years at most locations. As the GrassGro simulations used here are not regarded as definitive, these issues will be addressed during the next planned phase of generating new GrassGro output and deriving GRASP parameters.

Table 11. Correlation co-efficients (R^2) between simulated growth for GrassGro and GRASP. Results for two calibration stages are given (Stages 2 and 5) and for two growth periods: annual (1 Feb to 31 Jan) and eight months (1 Feb to 30 Sept).

Location	BoM station No.	Jan Stage 2	Jan Stage 5	Sept Stage 2	Sept Stage 5
		Phalaris optimisation set			
Bathurst	63005	0.64	0.65	0.65	0.63
Wellington	65035	0.63	0.68	0.43	0.40
Bega	69002	0.49	0.51	0.39	0.44
Goulburn	70263	0.75	0.70	0.63	0.58
Cooma	70278	0.74	0.72	0.75	0.61
Albury	72146	0.72	0.72	0.46	0.42
		Phalaris validation set			
Cowra	63023	0.69	0.67	0.42	0.35
Lithgow	63224	0.75	0.74	0.61	0.51
Orange	63231	0.72	0.76	0.50	0.54
Moss Vale	68045	0.83	0.67	0.69	0.46
Braidwood	69010	0.75	0.71	0.65	0.60
Crookwell	70025	0.73	0.77	0.44	0.50
Nimmitabel	70067	0.86	0.87	0.66	0.75
Yass	70091	0.63	0.59	0.48	0.42
Tumbarumba	72043	0.58	0.56	0.60	0.60
Tumut	72046	0.53	0.36	0.47	0.33
Binalong	73005	0.60	0.53	0.40	0.32
Cootamundra	73009	0.60	0.56	0.28	0.19
Grenfell	73014	0.70	0.64	0.58	0.42
Young	73056	0.61	0.57	0.45	0.37
Gundagai	73128	0.62	0.57	0.29	0.15
Lockhart	74064	0.62	0.61	0.36	0.27
Tocumwal	74106	0.71	0.69	0.35	0.29
Echuca	80015	0.75	0.66	0.55	0.39
		Fescue			
Gilgandra	51018	0.67	0.65	0.48	0.47
Barraba	54003	0.71	0.70	0.62	0.53
Manilla	55031	0.67	0.60	0.68	0.58
Quirindi	55049	0.59	0.66	0.56	0.61
Inverell	56017	0.79	0.78	0.71	0.69
Scone	61089	0.75	0.73	0.79	0.68
Singleton	61275	0.65	0.61	0.68	0.58
Mudgee	62021	0.72	0.73	0.55	0.53
Coonabarabran	64008	0.80	0.76	0.67	0.61
Dunedoo	64009	0.76	0.77	0.64	0.62
		Annual			
Condobolin	50052	0.76	0.80	0.58	0.58
Dubbo	65012	0.74	0.70	0.51	0.43
Forbes	65016	0.73	0.77	0.40	0.40
Parkes	65026	0.71	0.70	0.46	0.46
Temora	73038	0.76	0.77	0.36	0.39
Wyalong	73054	0.71	0.78	0.27	0.33
Coolamon	74033	0.75	0.74	0.56	0.47

8 Additional activities

As work on the temperate areas of NSW did not begin until the current Aussie GRASS project, the products are experimental and undergoing validation. As a result, extension of products to land managers was not undertaken. However, a 'Seasonal Assessment and Forecasting System' project with a two-year evaluation period will be undertaken commencing in 2001. This will build on the foundations laid during the Aussie GRASS project for both the lower rainfall, rangeland areas, and higher rainfall areas of NSW. The aim will be to produce output on a monthly basis from both the GRASP and GrassGro model. These products will be evaluated for their usefulness by a range of collaborators, with the longer term aim of making them available via the Internet and as printed material, as part of NSW Agriculture's monthly assessment and outlook of seasonal conditions for agricultural production across the State of NSW.

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10 Appendix 1: GrassGro parameter values for additional species (*Danthonia* & *Bothriochloa* are provisional)

Name	Unit	Description	White Clover	Lucerne winter dormant	Lucerne winter active	*Bothriochloa*	*Danthonia*	*Danthonia* Semi-arid
Annual			FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Grass			FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Legume			TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
Long Day			TRUE	TRUE	TRUE	FALSE	TRUE	TRUE
Develop								
K(V,1)	/d	rate of vernalisation at 0ºC	0.1				0.05	0.05
K(V,2)	/ºC	curvature of vernalisation rate with temperature	0.1				0.1	0.1
K(V,3)	ºC	base temperature for degree-day calculations	0	1	1	0	0	0
K(V,4)	hr	day length to initiate reproductive growth	12.5	12	12		10.3	10.3
K(V,5)	ºd	degree-days to initiate reproductive growth				800		
K(V,6)	ºd	degree-days to start of flowering	300	100	100	300	200	180
K(V,7)	d	maximum length of flowering period	50					
K(V,8)	0-1	effect of water stress on flowering duration	0.5					
K(V,9)	ºd	degree-days before reproduction can end	2800	2900	2900	3500	2800	3000
K(V,10)	0-1	soil moisture threshold for end of reproduction	0.1	0.5	0.5	0.5	0.4	0.5
K(V,11)	ºC	temperature threshold to break summer dormancy						
K(V,12)	0-1	soil moisture threshold to break summer dormancy						
K(V,13)	d	initial days of cool moist conditions for end of summer dormancy						
K(V,14)	d	days for summer dormancy requirement to reduce to zero						
K(V,15)	0-1	effect of drought on increasing time to flowering	0	0	0	0	0	0
K(V,16)	ºC	lagged temperature threshold to end phenological cycle	-50	-50	-50	11	-50	10
K(V,17)	hr	Daylength threshold to end winter-dormancy at 0ºC		10.5		10		
K(V,18)	hr/ºC	Decrease in winter-dormancy daylength threshold with temperature		0.2		0.2		
K(V,19)	0-1	Decrease in summer-dormancy moisture threshold after K(V,14) days						

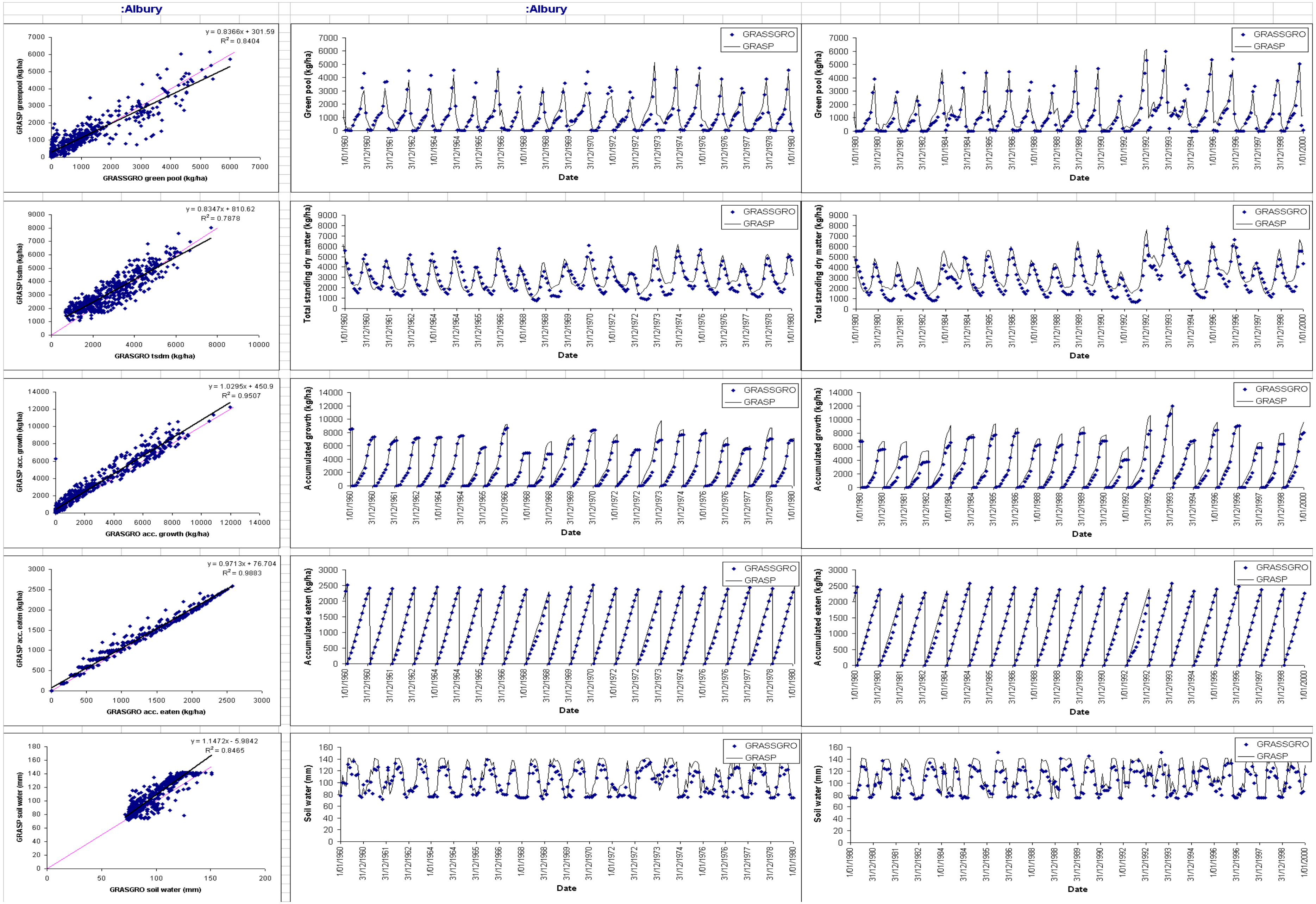
Name	Unit	Description	White Clover	Lucerne winter dormant	Lucerne winter active	*Bothriochloa*	*Danthonia*	*Danthonia* Semi-arid
Light								
1/K(I,1)	kg/ha	tissue weight required for LAI of 1	700	900	900	800	900	900
K(I,2)	0-1	relative contribution of stem to assimilation	0.4	0.5	0.5	0.1	0.2	0.2
20*K(I,3)	kg/ha/d	maximum assimilation at 20 MJ/m² radiation and 12 hr daylength	200	250	250	200	140	180
K(I,4)	MJ/m2/hr	effect of radiation intensity on radiation use efficiency	0.6	0.6	0.6	2	0.6	0.6
K(I,5)	(k)	light extinction coefficient under ungrazed conditions	0.8	0.75	0.75	0.6	0.6	0.6
K(I,6)	(k)	light extinction coefficient under heavily grazed conditions	0.95	0.95	0.95	0.85	0.9	0.9
Growth								
K(T,1)	ºC	lower temperature for 5% of maximum NPP	3	4	4	10	4	8
K(T,2)	ºC	lower temperature for 95% of maximum NPP	12	14.5	13	18	12	20
K(T,3)	ºC	upper temperature for 95% of maximum NPP	24	24	22	35	18	30
K(T,4)	ºC	upper temperature for 5% of maximum NPP	26	38	30	45	30	36
K(W,1)	0-1	ASW threshold for growth limitation	0.35	0.4	0.4	0.7	0.5	0.3
K(W,2)	0-1	ASW threshold for reduced transpiration	0.4	0.15	0.15	0.75	0.55	0.6
K(W,3)		curvature of waterlogging effect	23	23	23	23	23	23
K(W,4)	0-1	WFPS threshold for waterlogging effect	0.85	0.85	0.85	0.85	0.85	0.85
Alloc'n								
K(A,1)	R:S	target root:shoot ratio during vegetative growth	1.2	2	2	1.5	2	2
K(A,2)	R:S	target root:shoot ratio after flowering	0.8	1.2	1.2	0.8	1.5	1.5
K(A,3)	0-1	maximum allocation to reproductive structures	0.05					
K(A,4)	0-1	Maximum value of stem:shoot allocation	0.5	0.55	0.55	1.8	1.3	1.1
K(A,5)	%/d	maximum RGR of shoot in summer-dormant grasses						
K(A,6)	%/d	maximum RGR of root in summer-dormant grasses						
K(A,7)	0-1	proportion of stem or shoot at flowering to be relocated	0					
K(A,8)	ºd	degree-days for end of relocation from stem to repro. structures	0					
K(A,9)	0-1	Minimum value of stem:shoot allocation	0	0	0	0	0	0
K(U,1)	0-1	threshold growth limit for remobilization from below ground	0.4	0.4	0.4	0.25	0.6	0.6
K(U,2)	%/d	relative rate of remobilization from below ground	1	2	2	2	1	1

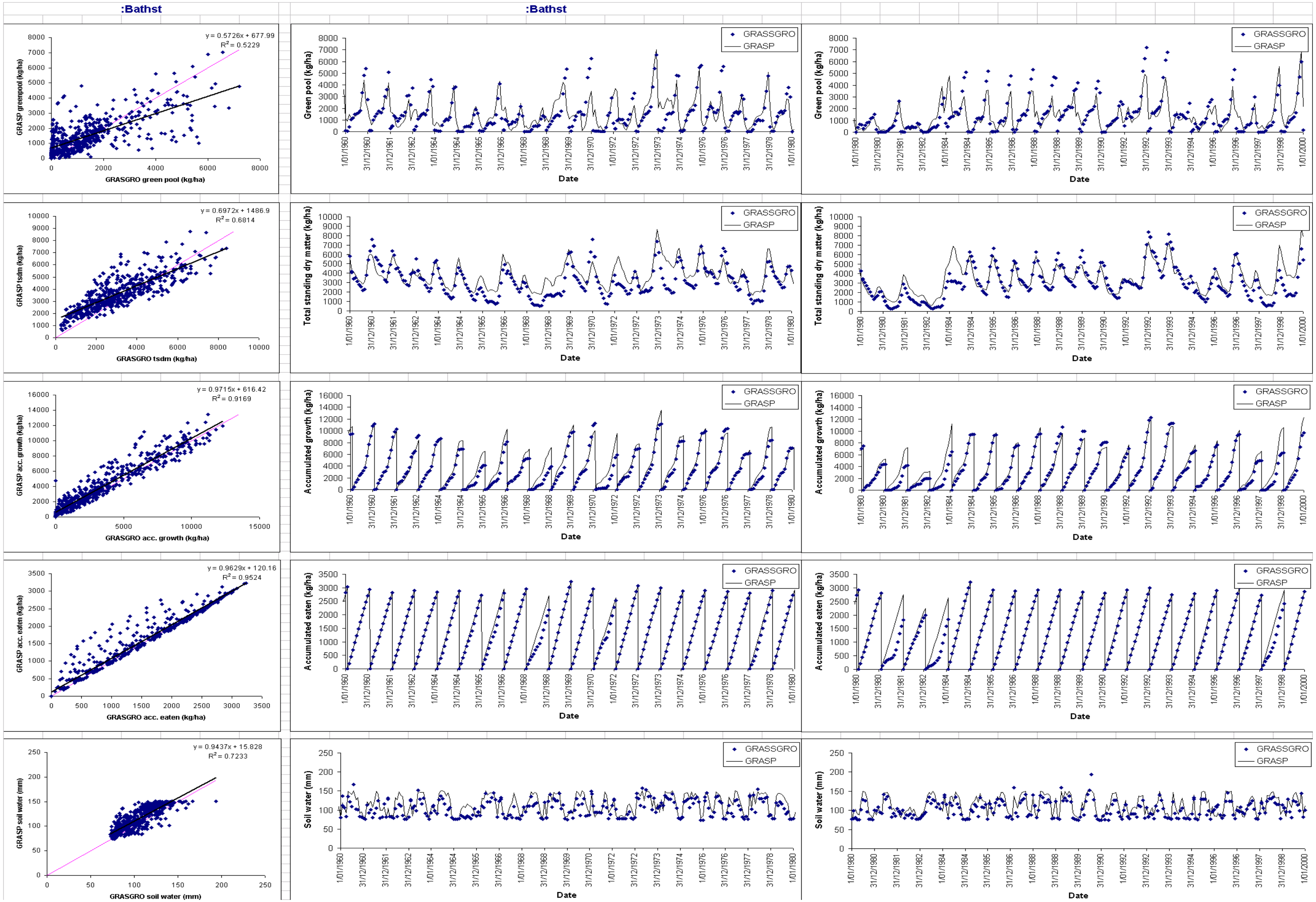
Name	Unit	Description	White Clover	Lucerne winter dormant	Lucerne winter active	*Bothriochloa*	*Danthonia*	*Danthonia* Semi-arid
Death								
K(D,1,l,lf)	%/d	death rate of live leaf (shoot in grasses)	1	0.4	0.4	0.05	0.3	0.3
K(D,1,l,st)	%/d	death rate of live stem (ignore in grasses)	1	0.3	0.3	0.01	0.03	0.03
K(D,1,s,lf)	%/d	death rate of senescing leaf (shoot in grasses)	50	15	15	1	20	10
K(D,1,s,st)	%/d	death rate of senescing stem (ignore in grasses)	50	1	1	0.01	1	1
K(D,2)	ºC	temperature for 5% mortality at the first frost	0	0	-2	-3	-3	-3
K(D,3)	ºC	temperature for 95% mortality at the first frost	-11	-3	-11	-15	-11	-11
K(D,4)	ºC	frost-hardening factor	1	1	1	1	1	1
K(F,1,lf)	%/d	maximum specific fall rate of leaf (shoot in grasses) from rain	10	10	10	3	3	3
K(F,1,st)	%/d	maximum specific fall rate of stem from rain (ignore in grasses)	3	3	3	0.5	0.5	0.5
K(F,2,lf)		curvature of fall rate-rain relationship for leaf (shoot)	0.1	0.1	0.1	0.1	0.1	0.1
K(F,2,st)		curvature of fall rate-rain relationship for stem	0.1	0.1	0.1	0.1	0.1	0.1
K(F,3,lf)	%/dse/d	effect of trampling on fall of dead leaf (shoot in grasses)	0.05	0.05	0.05	0.01	0.01	0.01
K(F,3,st)	%/dse/d	effect of trampling on fall of dead stem (ignore in grasses)	0.02	0.02	0.02	0.005	0.005	0.005
K(R,1)	%/d	specific root death rate at 10ºC	0.5	0.25	0.25	0.3	0.3	0.3
K(R,2)	Q10	Q10 for root death rate	1.5	1.5	1.5	1.5	1.5	1.5
DMA								
K(M,1,l,lf)	DU/d	decline rate of 60% DMD live leaf (shoot) with no water stress	0.06	0.04	0.04	0.15	0.1	0.1
K(M,1,l,st)	DU/d	decline rate of 60% DMD live stem with no water stress	0.15	0.09	0.09	0.6	0.5	0.5
K(M,1,s,lf)	DU/d	decline rate of 60% DMD senescing leaf (shoot) with no water stress	1	1	1	0.15	0.15	0.15
K(M,1,s,st)	DU/d	decline rate of 60% DMD senescing stem with no water stress	0.5	0.3	0.3	0.6	0.5	0.5
K(M,2)	Q10	Q10 for digestibility decline of live and senescing material	2	2	2	2.5	2	2
K(M,3,lf)		effect of ASW on decline rate of live and senescing leaf (shoot)	1	1	1	1	1	1
K(M,3,st)		effect of ASW on decline rate of live and senescing stem	1	1	1	1	1	1
K(Y,1,lf)	DU/d	decline rate for 60% DMD dead leaf (shoot) under dry conditions	0.1	0.25	0.25	0.15	0.05	0.05
K(Y,1,st)	DU/d	decline rate for 60% DMD dead stem under dry conditions	0.1	0.2	0.2	0.3	0.15	0.15
K(Y,2,lf)	DU/d	effect of moist conditions on decline rate of 60% DMD dead leaf (shoot)	0.5	0.65	0.65	0.9	0.25	0.25
K(Y,2,st)	DU/d	effect of moist conditions on decline rate of 60% DMD dead stem	0.35	0.65	0.65	0.9	0.15	0.15

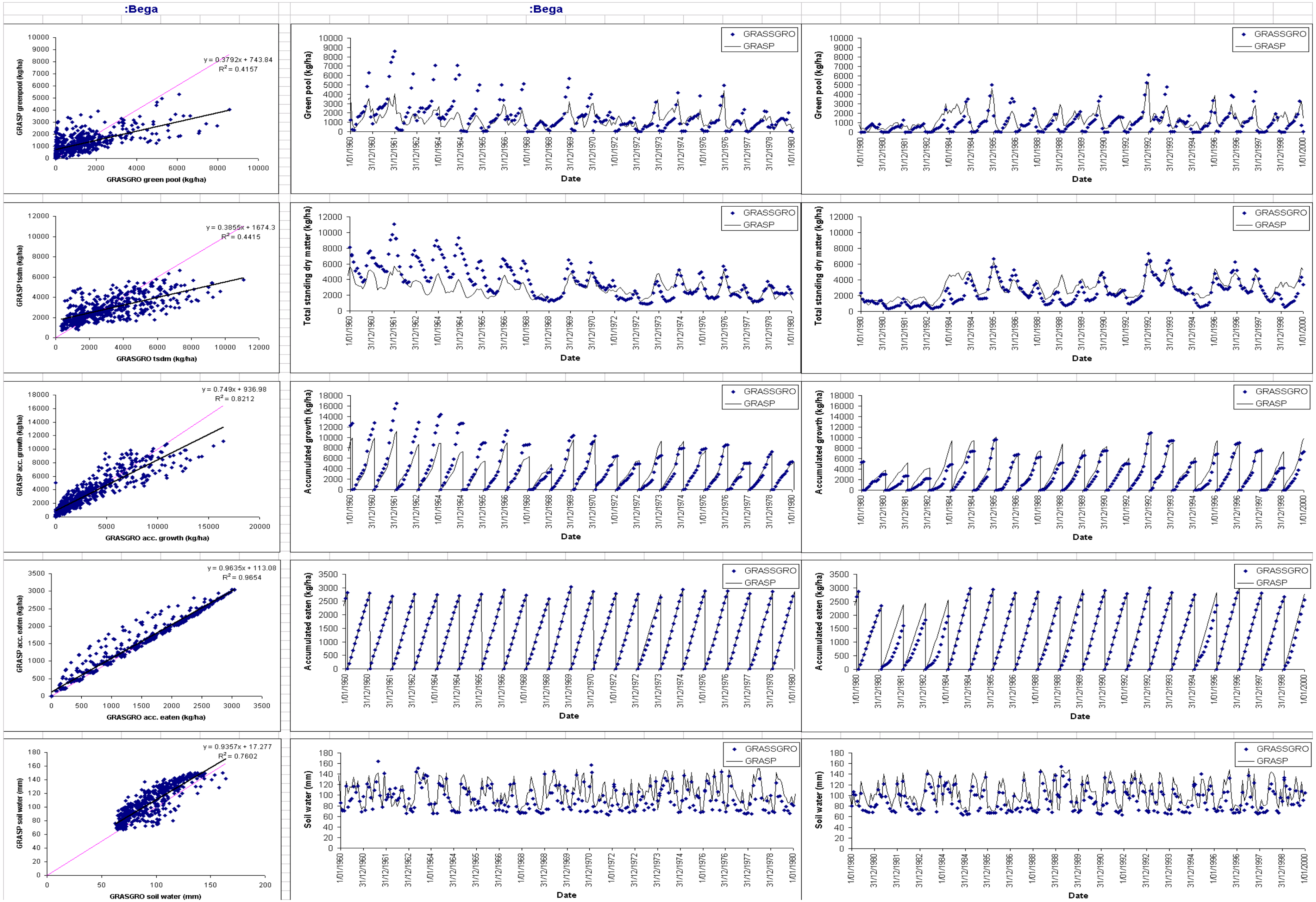
Name	Unit	Description	White Clover	Lucerne winter dormant	Lucerne winter active	*Bothriochloa*	*Danthonia*	*Danthonia* Semi-arid
K(L,1)	DU/d	Max. rate of litter digestibility decline under dry conditions	0.04	0.25	0.25	0.03	0.02	0.02
K(L,2)	DU/d	Max. rate of litter digestibility decline under wet conditions	3	3	3	0.5	1	1
K(L,3)	ºC	Temperature for 5% of max. rate of litter digestibility decline	0	0	0	0	0	0
K(L,4)	ºC	Temperature for 95% of max. rate of litter digestibility decline	8	8	8	8	8	8
K(Q,80%)		Scalar for digestibility decline of 80% DMD tissue	1.5	1	1	7	1.5	1.5
K(Q,70%)		Scalar for digestibility decline of 70% DMD tissue	1.25	1	1	4	1.25	1.25
K(Q,50%)		Scalar for digestibility decline of 50% DMD tissue	1	1	1	0.5	1.1	1.1
K(Q,40%)		Scalar for digestibility decline of 40% DMD tissue	1	1	1	0.4	1	1
Seeds								
K(S,1)	%/d	rate of 'hardening' of immature seeds	6					
K(S,2)	d	length of period of innate dormancy	60					
K(S,3)	%/ºC/d	effect of maximum temperature on seed 'softening'	0.5					
K(S,4)	ºC	threshold maximum temperature for seed 'softening'	28					
K(S,5,s)	%/d	specific death rate for soft seeds	1					
K(S,5,h)	%/d	specific death rate for hard seeds	0.01					
K(G,1)	0-1	surface ASW above which germination takes place	0.35					
K(G,2)	ºC	minimum temperature for germination	5					
K(G,3)	ºC	lower bound of optimal temperature range for germination	13					
K(G,4)	ºC	upper bound of optimal temperature range for germination	25					
K(G,5)	ºC	maximum temperature for germination	30					
K(G,6)	d	time to first seedling emergence under optimal conditions	8					
K(G,7)	d	time to complete seedling emergence under optimal conditions	20					
K(G,8)	%	proportion of reproductive structures which is actually seed	80					
K(Z,1)	0-1	value of the seedling stress index at which mortalities begin	0.75					
K(Z,2)	0-1	value of the seedling stress index for 100% seedling mortality	1					
K(Z,3)	d	establishment scalar	3.4					

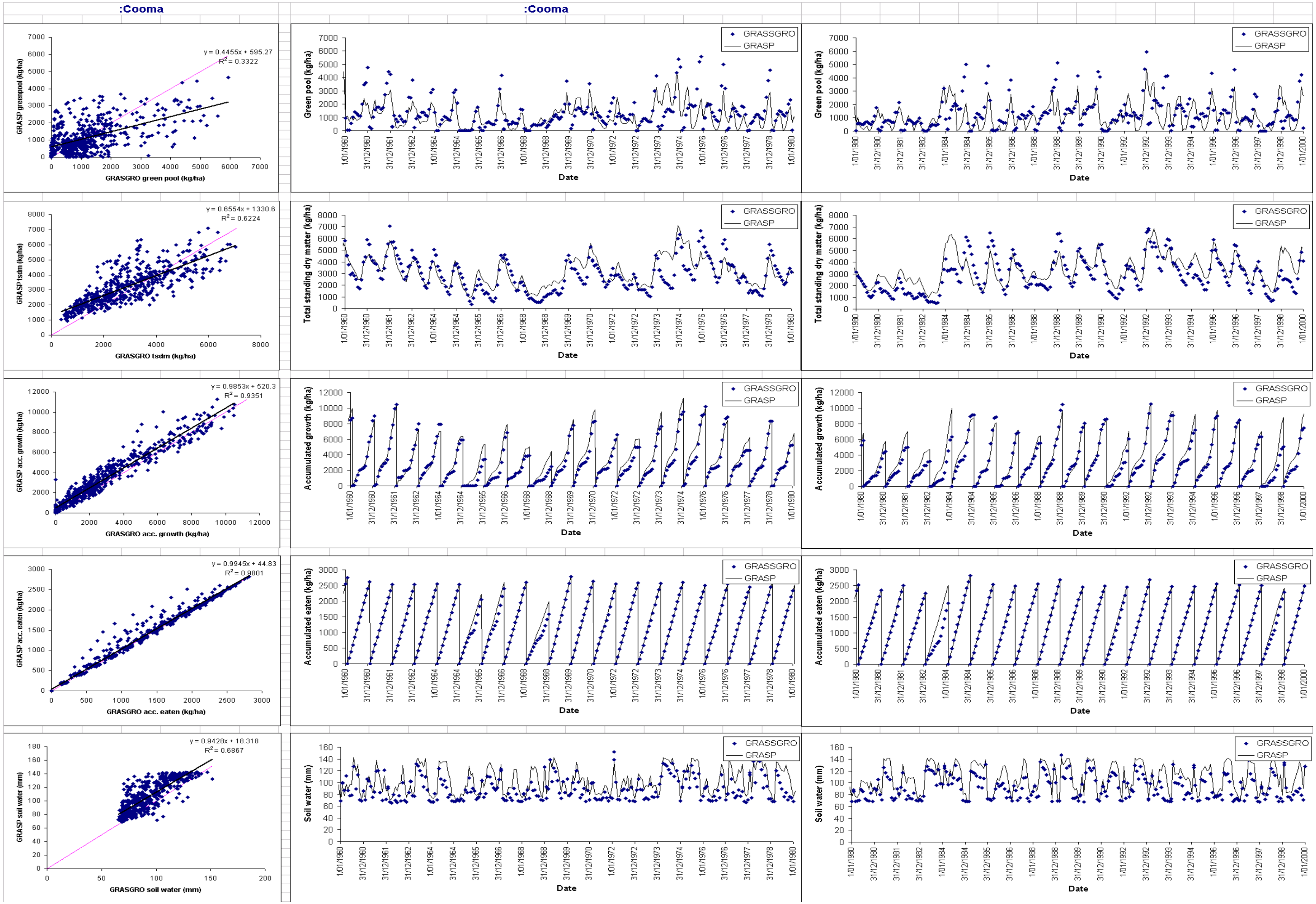
Name	Unit	Description	White Clover	Lucerne winter dormant	Lucerne winter active	*Bothriochloa*	*Danthonia*	*Danthonia* Semi-arid
Other								
Root max	mm	parameter for estimating rooting depth	550	3000	3000	1500	850	850
SF		'selection factor' (1.7 for improved species)	0	0	0	0	0	0
HF		'height factor' (min. 1.0)	1	1.6	1.6	2	1.4	1.4
CP(80%)	%	crude protein content of 80% digestible herbage	33	33	33	25	25	25
CP(70%)	%	crude protein content of 70% digestible herbage	24	24	24	18	18	18
CP(60%)	%	crude protein content of 60% digestible herbage	16	16	16	12	12	12
CP(50%)	%	crude protein content of 50% digestible herbage	9	9	9	7	7	7
CP(40%)	%	crude protein content of 40% digestible herbage	4	4	4	3	3	3
dg(80%)	%	protein degradability in 80% digestible herbage	90	90	90	90	90	90
dg(70%)	%	protein degradability in 70% digestible herbage	80	80	80	80	80	80
dg(60%)	%	protein degradability in 60% digestible herbage	70	70	70	70	70	70
dg(50%)	%	protein degradability in 50% digestible herbage	60	60	60	60	60	60
dg(40%)	%	protein degradability in 40% digestible herbage	50	50	50	50	50	50
RQ(s,u)	1-Jun	equivalent digestibility class for unripe seeds (may be blank)	5					
RQ(s,r)	1-Jun	equivalent digestibility class for ripe seeds (may be blank)	6					
DMD(s,u)	%	DM digestibility of unripe diaspores	45					
DMD(s,r)	%	DM digestibility of ripe diaspores	55					
CP(s)	%	Crude protein content of diaspores	25					

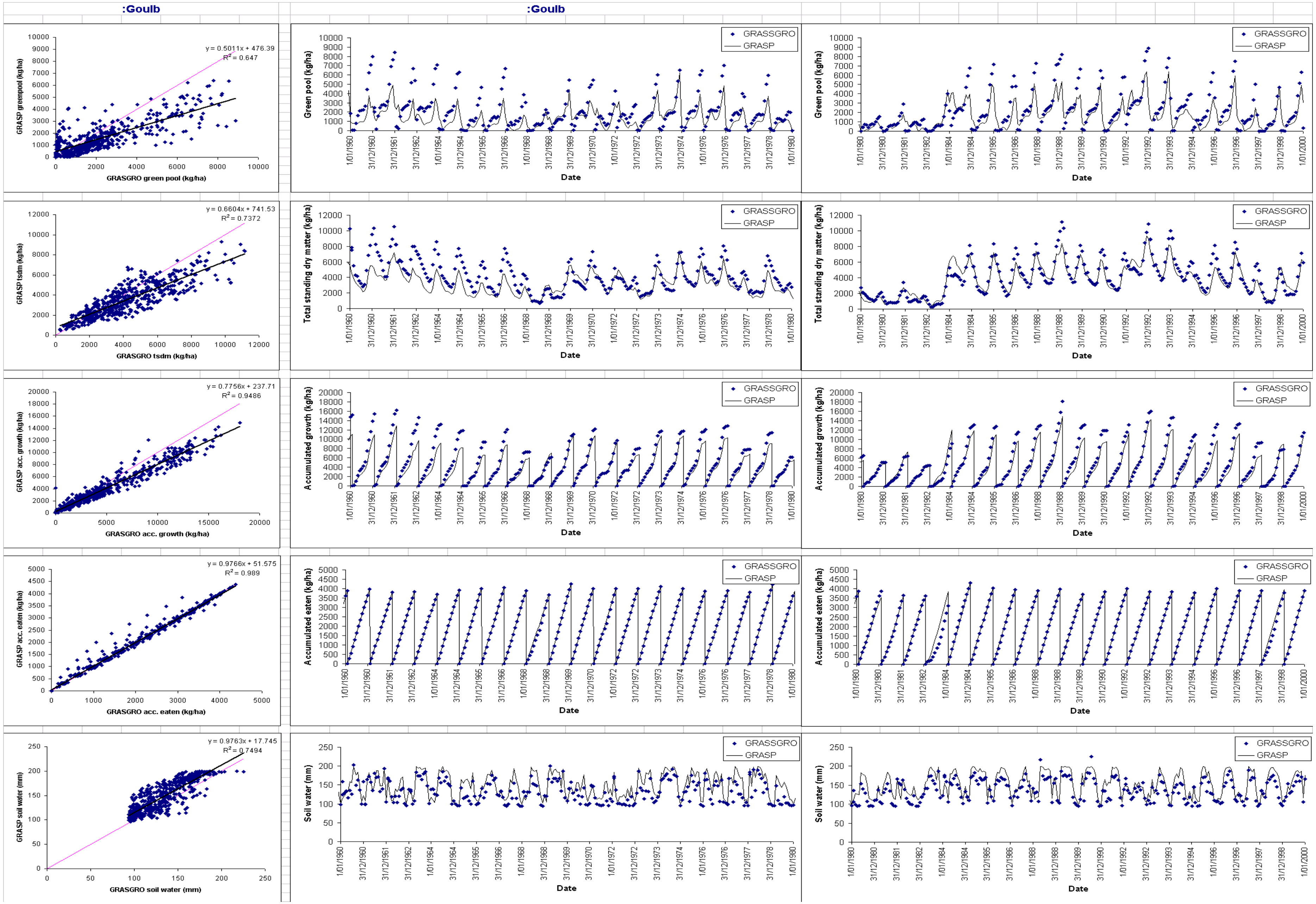
11 Appendix 2: Time series graphs of GRASP and GrassGro simulated variables

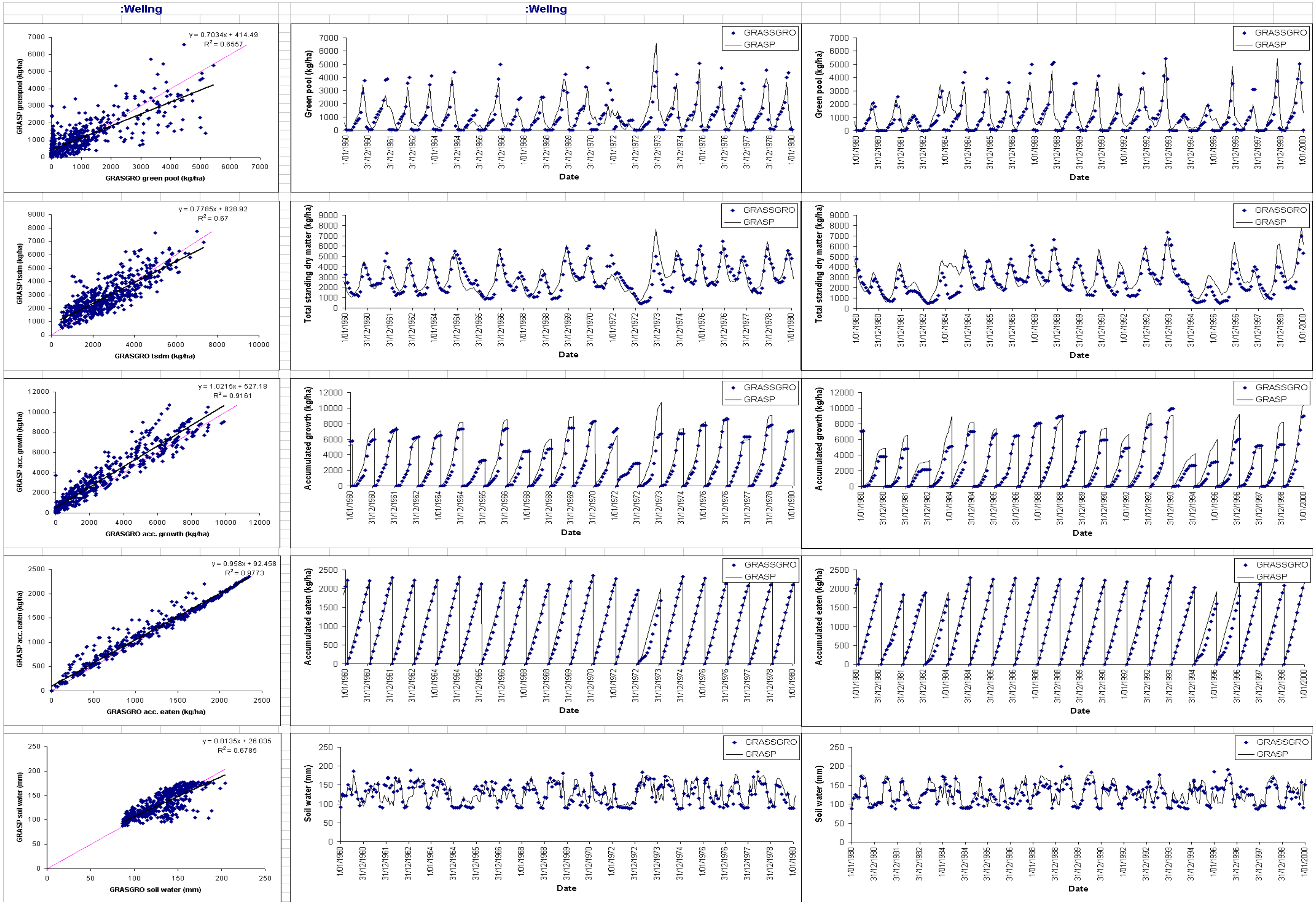

:Albury
:Albury
y = 0.8366x + 301.59
R^2 = 0.8404
GRASP greenpool (kg/ha)
GRASSGRO green pool (kg/ha)
y = 0.8347x + 810.62
R^2 = 0.7878
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.0295x + 450.9
R^2 = 0.9507
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9713x + 76.704
R^2 = 0.9883
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.1472x - 5.9842
R^2 = 0.8465
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

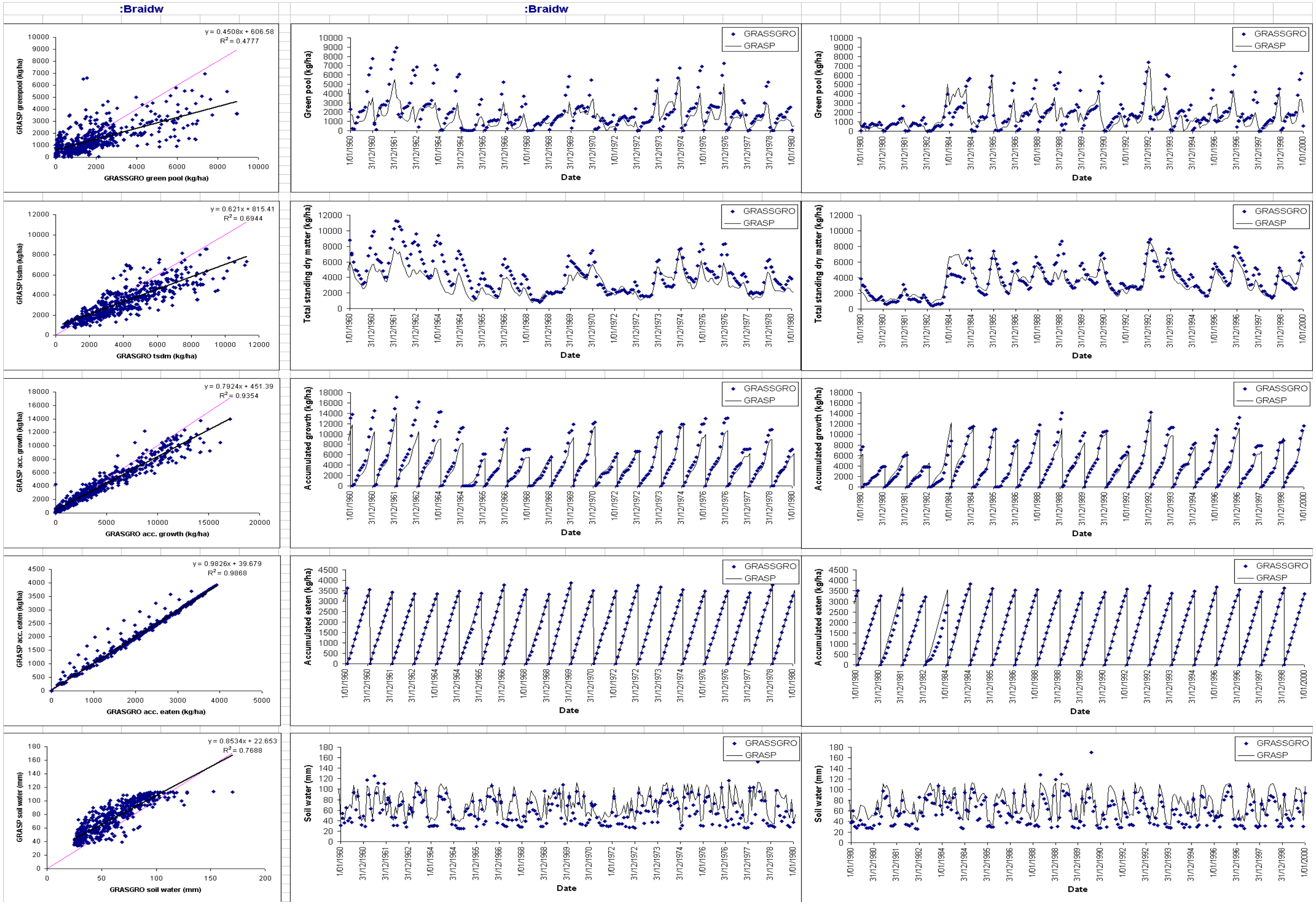

:Bathst
:Bathst
y = 0.5726x + 677.99
R^2 = 0.5229
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
Green pool (kg/ha)
y = 0.6972x + 1486.9
R^2 = 0.6814
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
Total standing dry matter (kg/ha)
y = 0.9715x + 616.42
R^2 = 0.9169
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
Accumulated growth (kg/ha)
y = 0.9629x + 120.16
R^2 = 0.9524
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
Accumulated eaten (kg/ha)
y = 0.9437x + 15.828
R^2 = 0.7233
GRASP soil water (mm)
GRASGRO soil water (mm)
Soil water (mm)
GRASSGRO
GRASP
Date

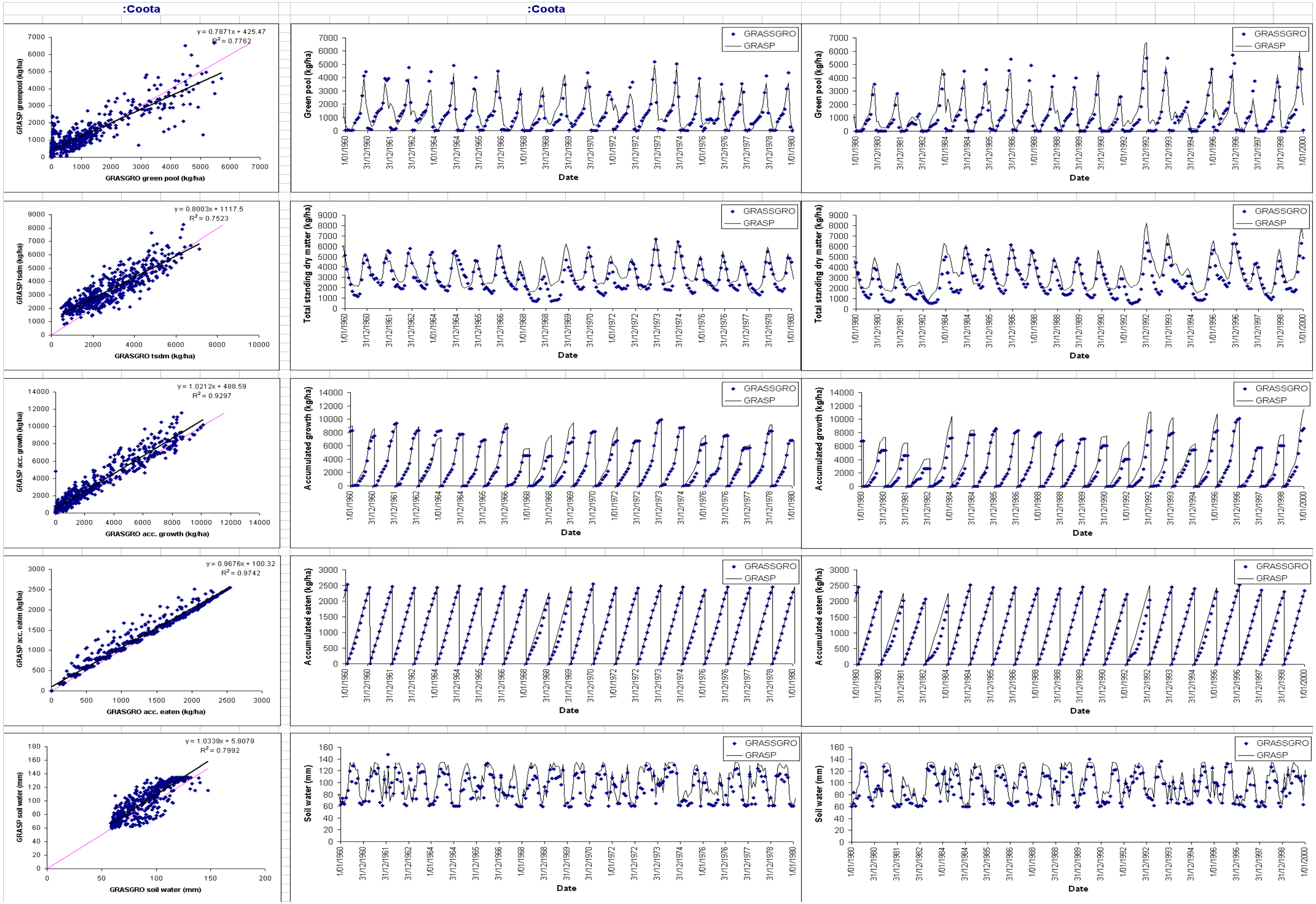

:Bega
:Bega
y = 0.3792x + 743.84
R² = 0.4157
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.3855x + 1674.3
R² = 0.4415
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.749x + 936.98
R² = 0.8212
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9635x + 113.08
R² = 0.9654
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9357x + 17.277
R² = 0.7602
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

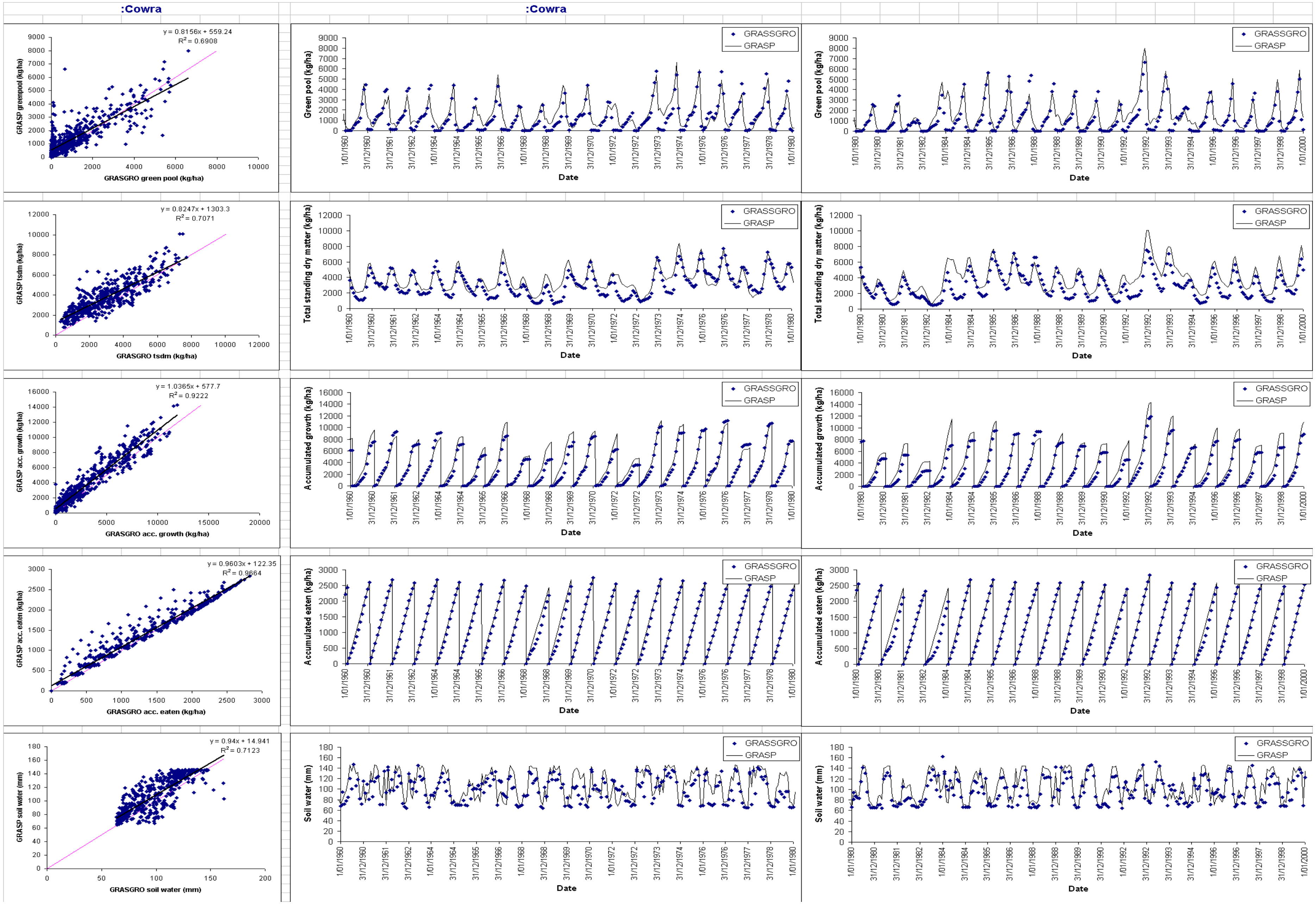

:Cooma
:Cooma
y = 0.4455x + 595.27
R^2 = 0.3322
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
Green pool (kg/ha)
y = 0.6554x + 1330.6
R^2 = 0.6224
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
Total standing dry matter (kg/ha)
y = 0.9853x + 520.3
R^2 = 0.9351
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
Accumulated growth (kg/ha)
y = 0.9945x + 44.83
R^2 = 0.9801
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
Accumulated eaten (kg/ha)
y = 0.9428x + 18.318
R^2 = 0.6867
GRASP soil water (mm)
GRASGRO soil water (mm)
Soil water (mm)
GRASSGRO
GRASP
Date

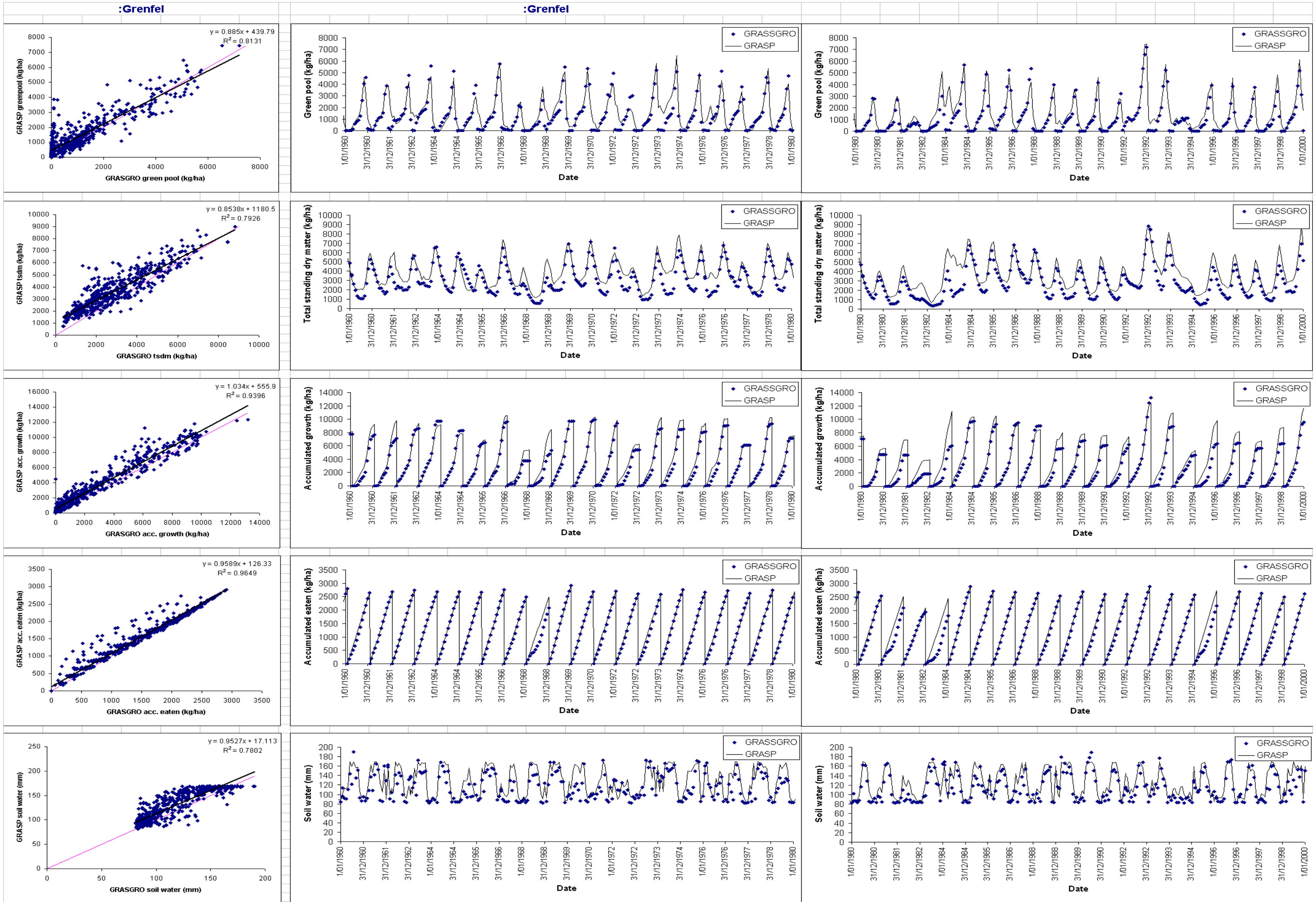

:Goulb
:Goulb
y = 0.5011x + 476.39
R² = 0.647
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.6604x + 741.53
R² = 0.7372
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.7756x + 237.71
R² = 0.9486
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9766x + 51.575
R² = 0.989
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9763x + 17.745
R² = 0.7494
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP

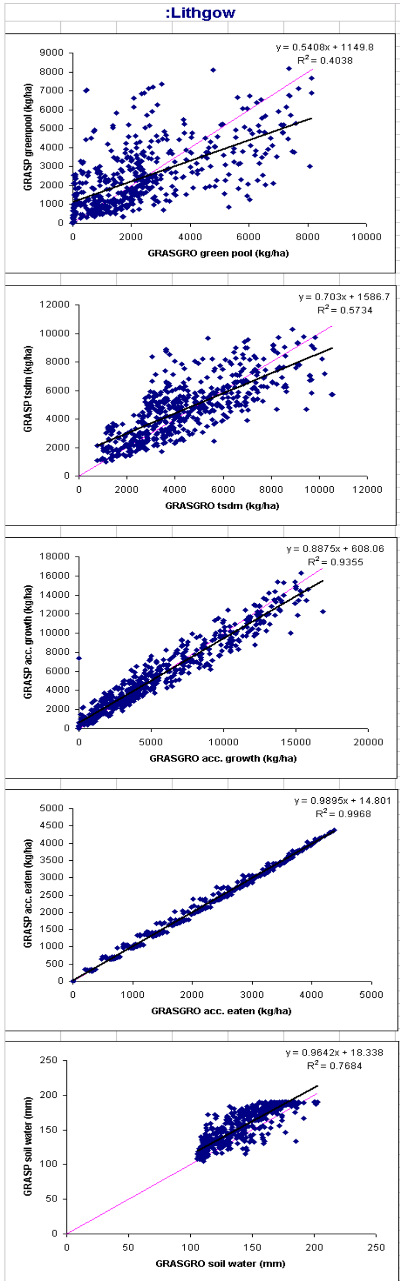

:Welling
:Welling
y = 0.7034x + 414.49
R^2 = 0.6557
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
Green pool (kg/ha)
y = 0.7785x + 828.92
R^2 = 0.67
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
Total standing dry matter (kg/ha)
y = 1.0215x + 527.18
R^2 = 0.9161
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
Accumulated growth (kg/ha)
y = 0.958x + 92.458
R^2 = 0.9773
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
Accumulated eaten (kg/ha)
y = 0.8135x + 26.035
R^2 = 0.6785
GRASP soil water (mm)
GRASGRO soil water (mm)
Soil water (mm)
GRASSGRO
GRASP
Date

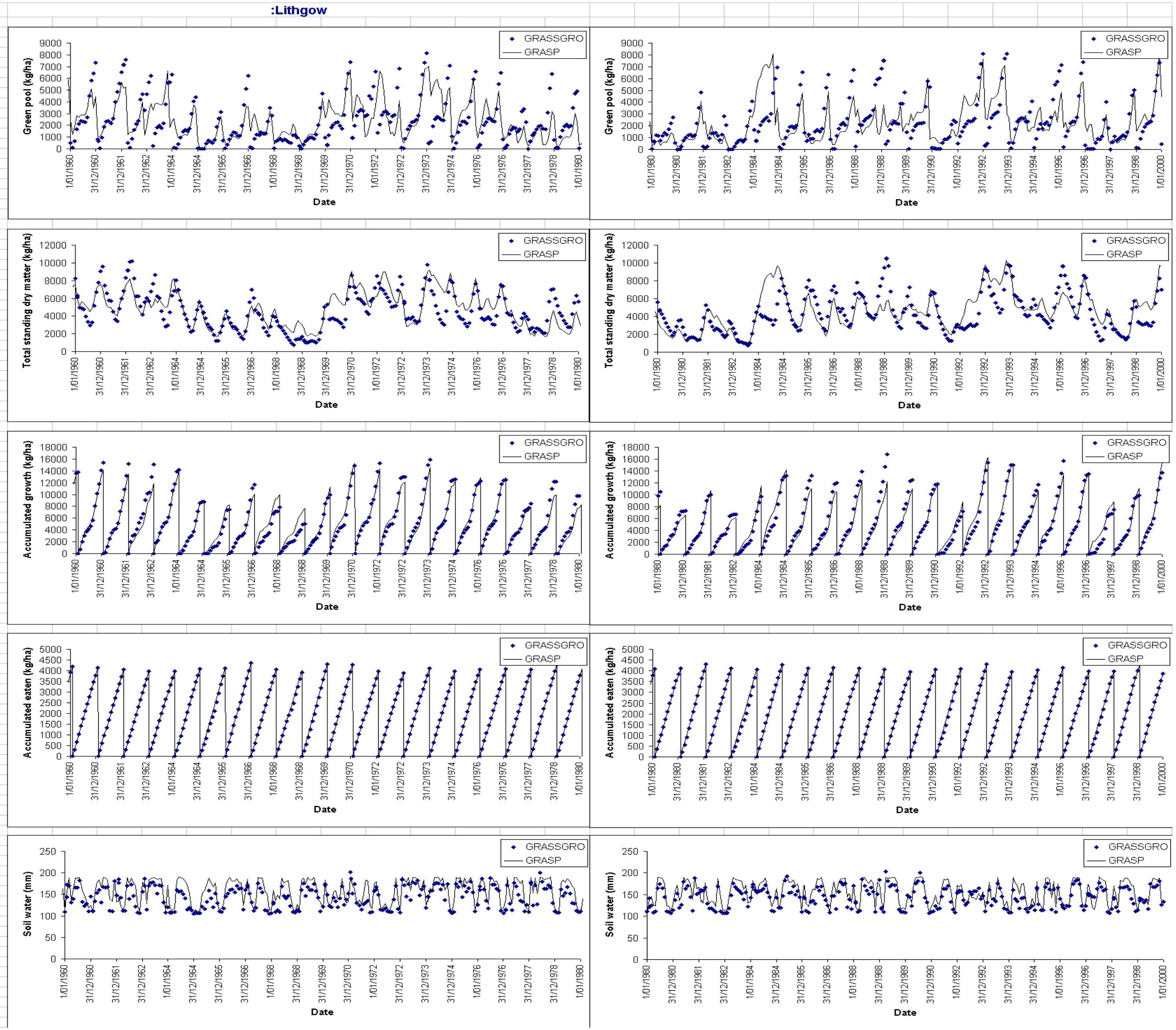

:Braidw
:Braidw
y = 0.4508x + 606.58
R^2 = 0.4777
GRASP greenpool (kg/ha)
GRASSGRO green pool (kg/ha)
y = 0.621x + 815.41
R^2 = 0.6944
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.7924x + 451.39
R^2 = 0.9354
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9826x + 39.679
R^2 = 0.9868
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.8534x + 22.653
R^2 = 0.7688
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
GRASSGRO
GRASP
Date

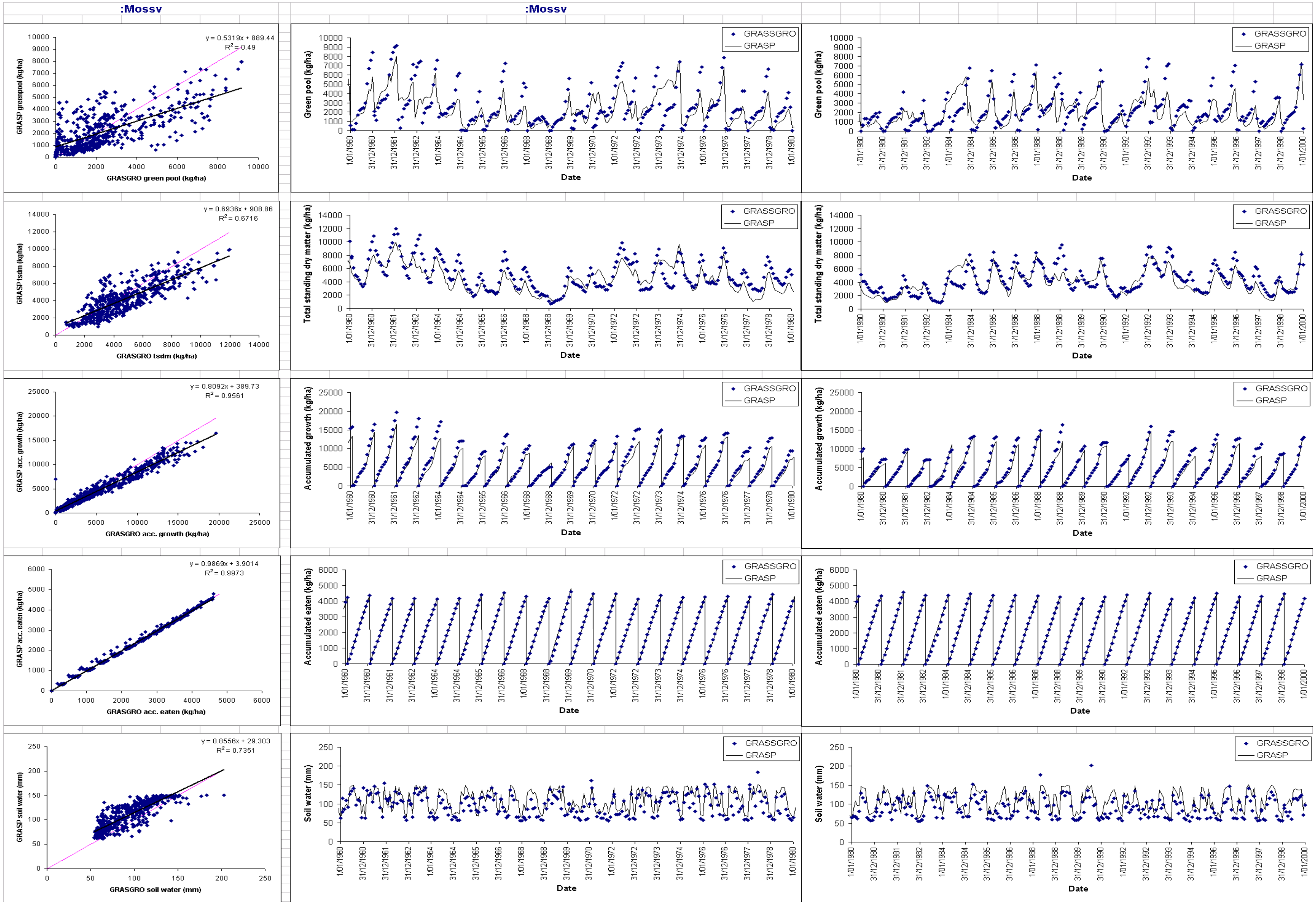

:Coota
:Coota
y = 0.7871x + 425.47
R² = 0.7762
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.8003x + 1117.5
R² = 0.7523
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.0212x + 488.59
R² = 0.9297
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9676x + 100.32
R² = 0.9742
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.0339x + 5.8079
R² = 0.7992
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP

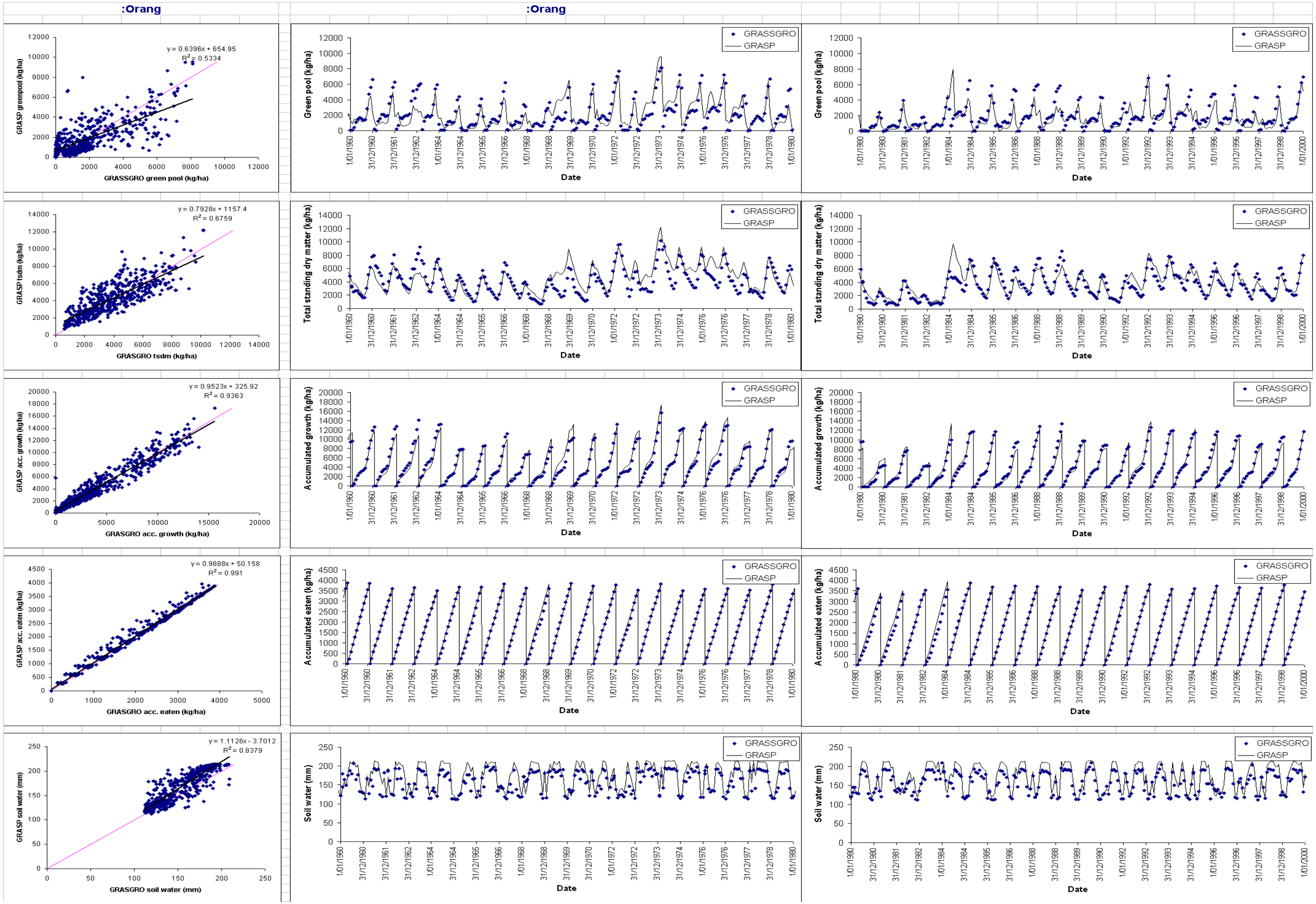

:Cowra
:Cowra
y = 0.8156x + 559.24
R^2 = 0.6908
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.8247x + 1303.3
R^2 = 0.7071
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.0365x + 577.7
R^2 = 0.9222
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9603x + 122.35
R^2 = 0.9664
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.94x + 14.941
R^2 = 0.7123
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

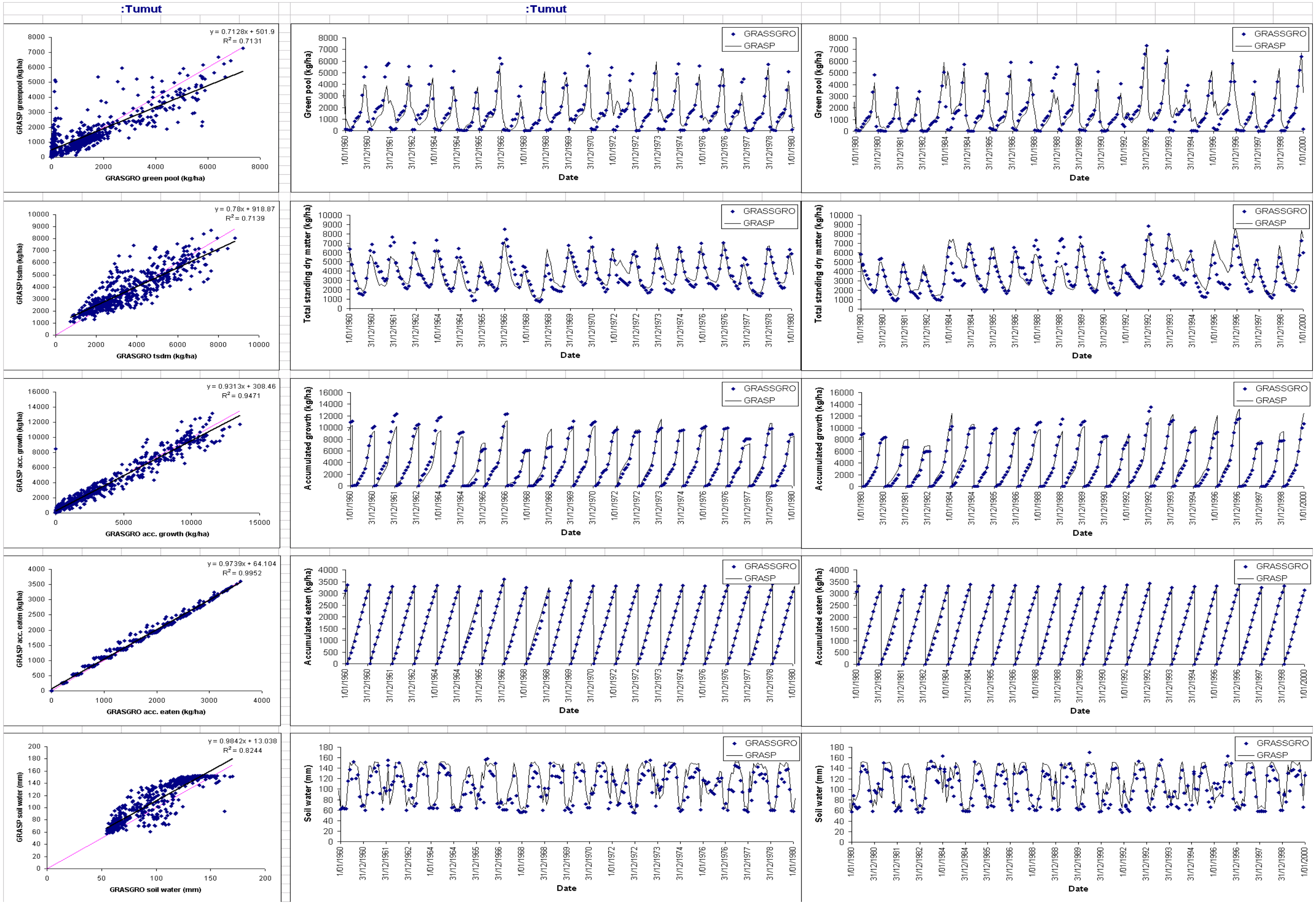

:Grenfel
:Grenfel
y = 0.885x + 439.79
R² = 0.8131
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.8538x + 1180.5
R² = 0.7926
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.034x + 555.9
R² = 0.9396
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9589x + 126.33
R² = 0.9649
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9527x + 17.113
R² = 0.7802
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

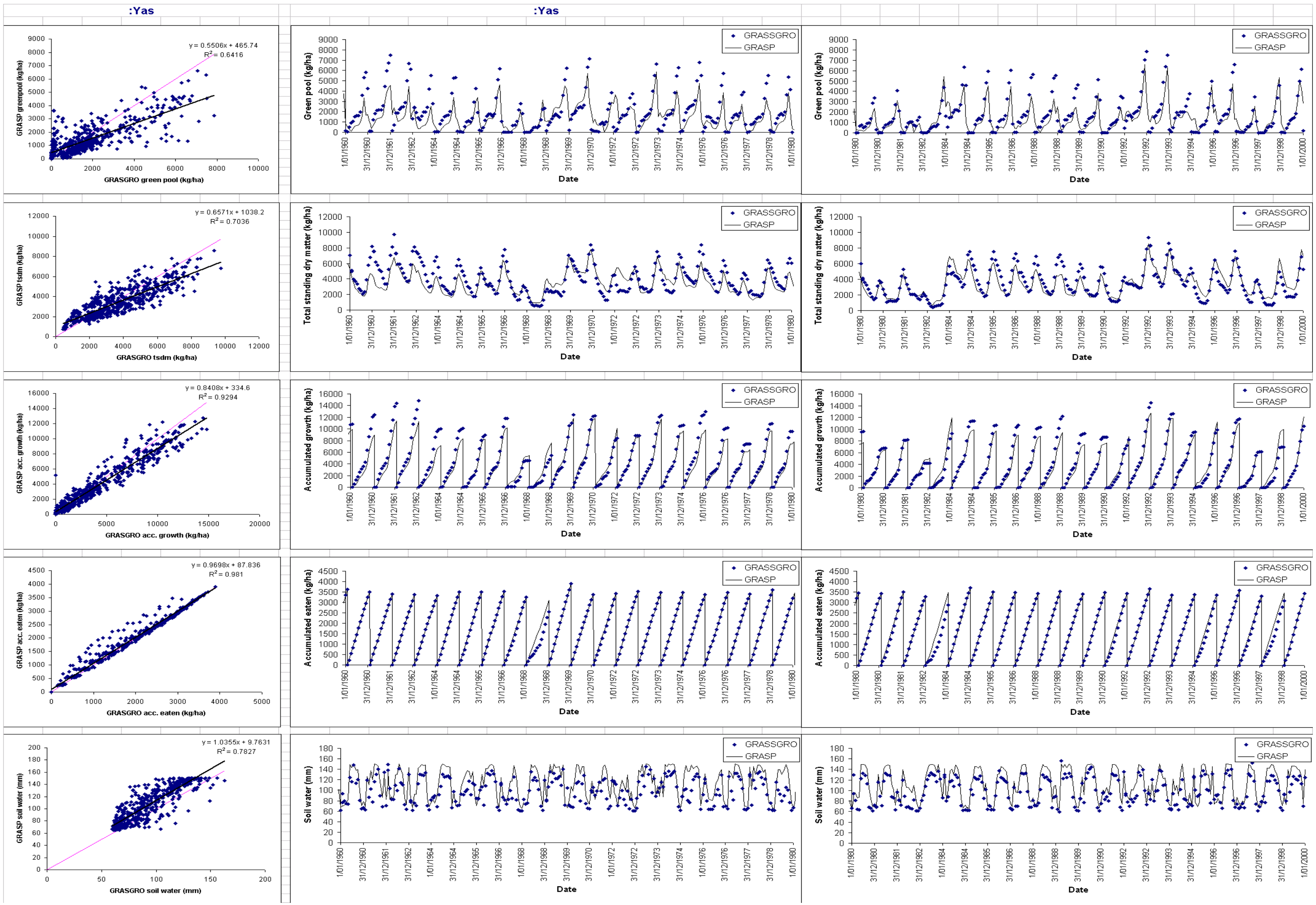

:Lithgow
y = 0.5408x + 1149.8
R^2 = 0.4038
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.703x + 1586.7
R^2 = 0.5734
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.8875x + 608.06
R^2 = 0.9355
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9895x + 14.801
R^2 = 0.9968
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9642x + 18.338
R^2 = 0.7684
GRASP soil water (mm)
GRASGRO soil water (mm)

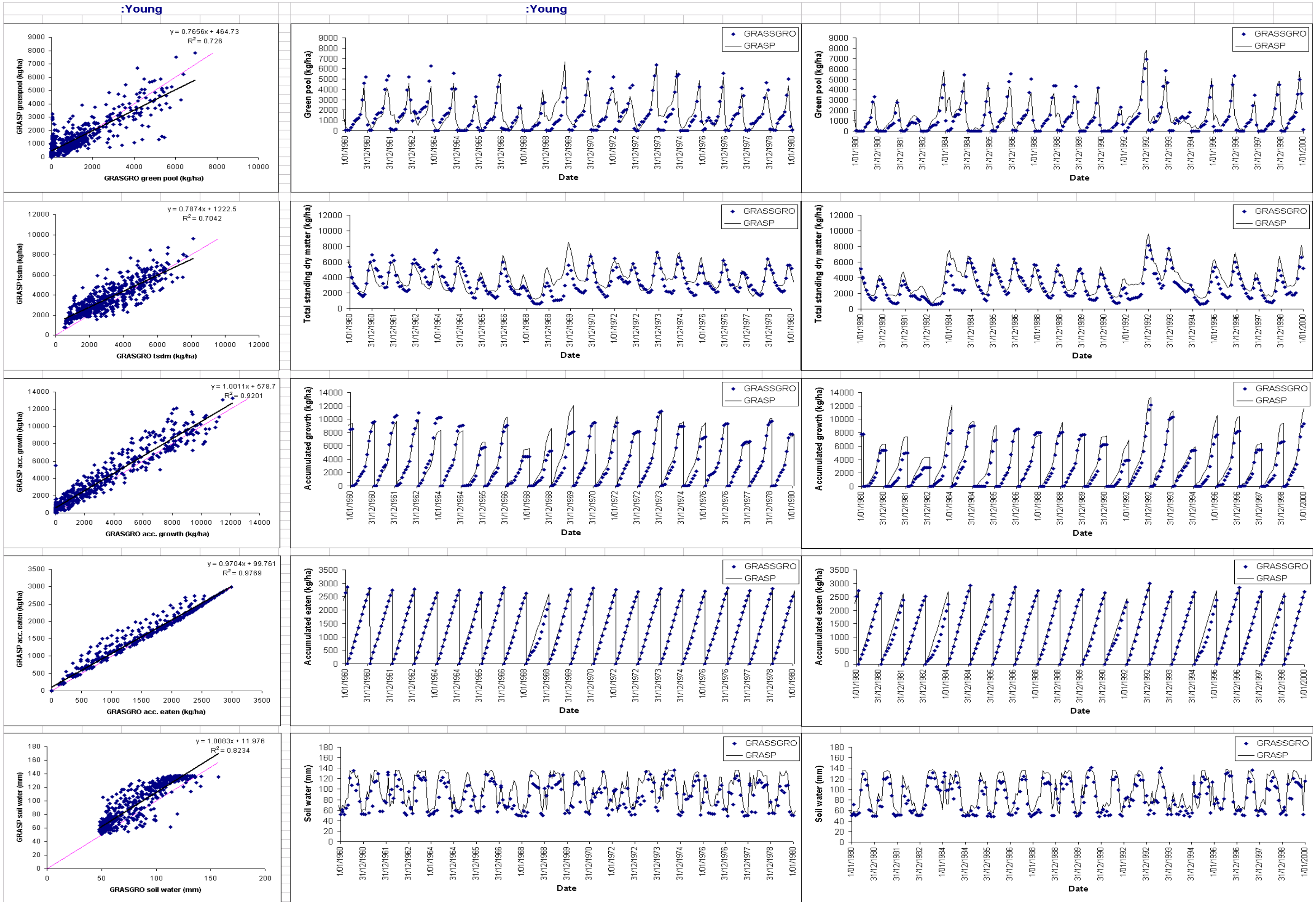

:Lithgow
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

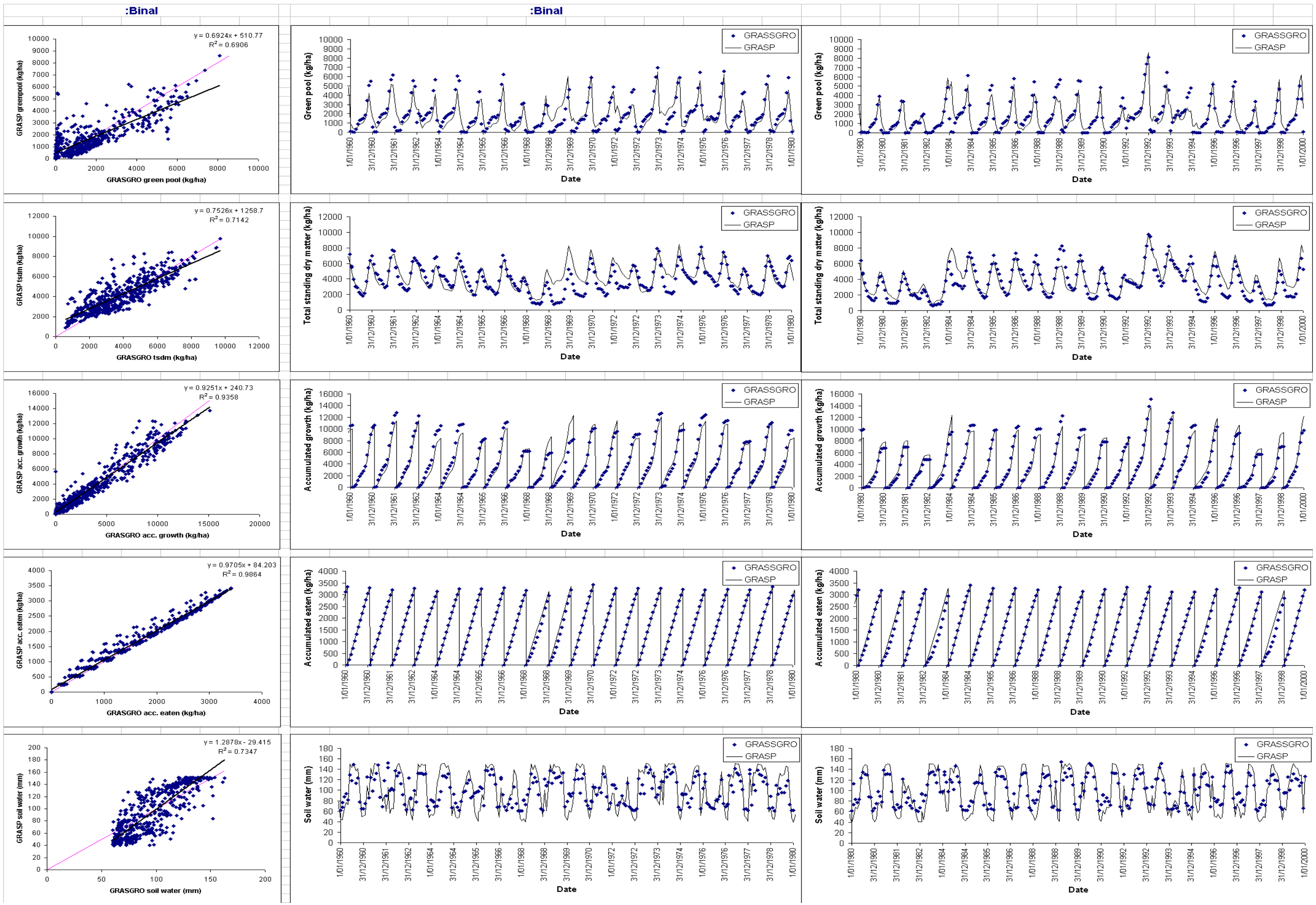

:Mossv
:Mossv
y = 0.5319x + 889.44
R^2 = 0.49
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.6936x + 908.86
R^2 = 0.6716
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.8092x + 389.73
R^2 = 0.9561
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9869x + 3.9014
R^2 = 0.9973
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.8556x + 29.303
R^2 = 0.7351
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP

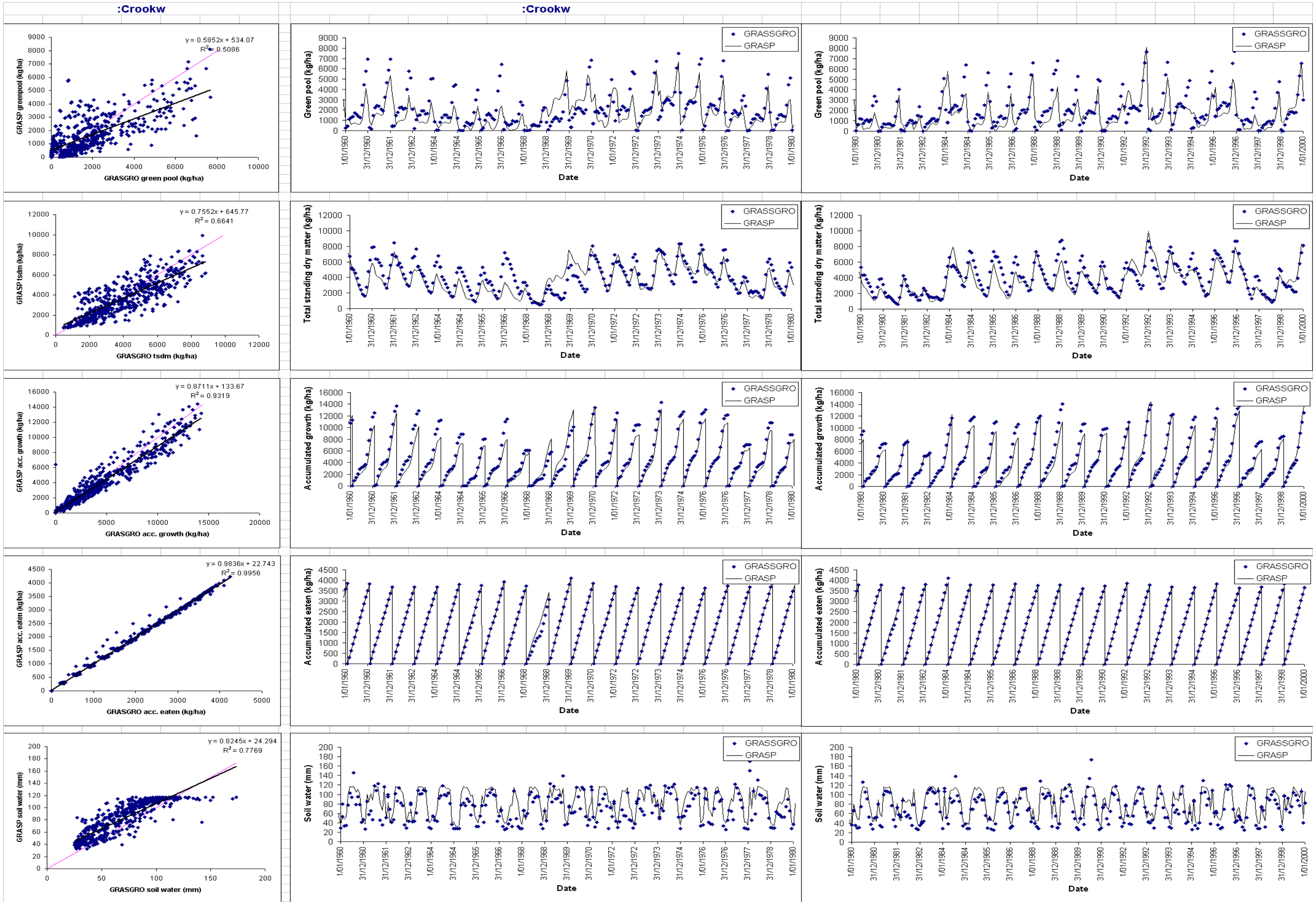

:Orang
:Orang
y = 0.6396x + 654.95
R^2 = 0.5334
GRASP greenpool (kg/ha)
GRASSGRO green pool (kg/ha)
y = 0.7928x + 1157.4
R^2 = 0.6759
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.9523x + 325.92
R^2 = 0.9363
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9888x + 50.158
R^2 = 0.991
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.1126x - 3.7012
R^2 = 0.8379
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP

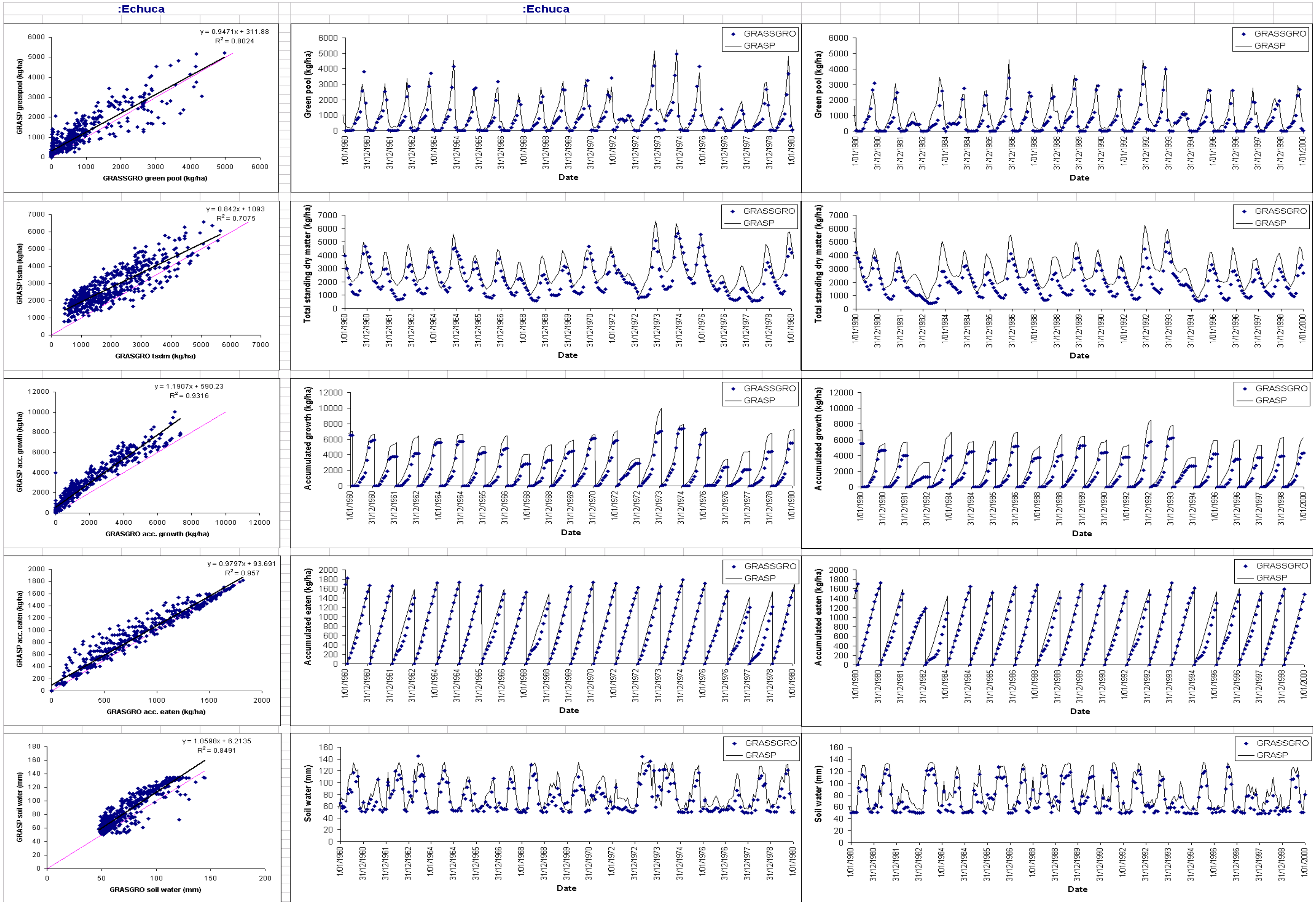

:Tumut
:Tumut
y = 0.7128x + 501.9
R^2 = 0.7131
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.78x + 918.87
R^2 = 0.7139
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.9313x + 308.46
R^2 = 0.9471
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9739x + 64.104
R^2 = 0.9952
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9842x + 13.038
R^2 = 0.8244
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

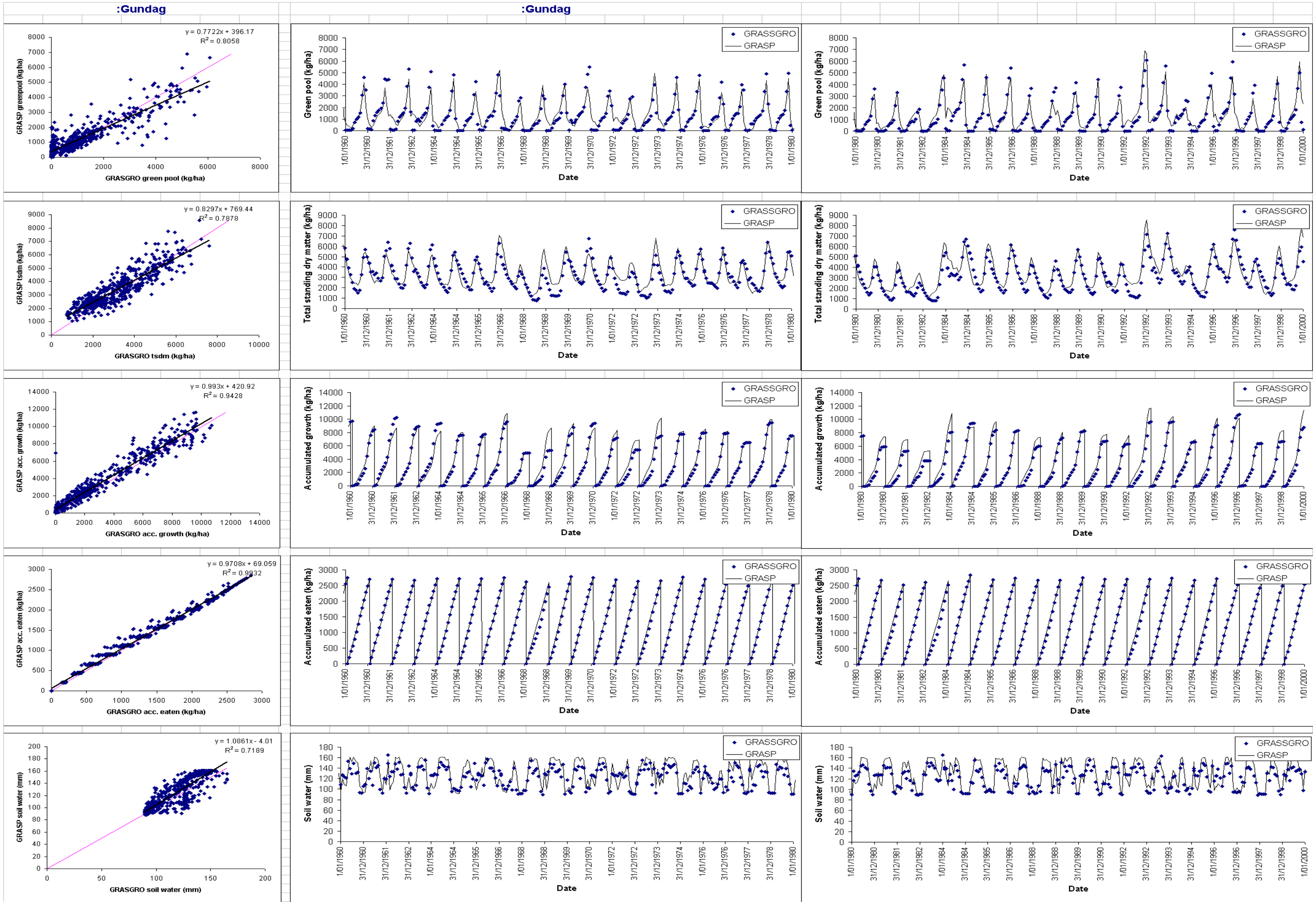

:Yas
:Yas
y = 0.5506x + 465.74
R^2 = 0.6416
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.6571x + 1038.2
R^2 = 0.7036
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.8408x + 334.6
R^2 = 0.9294
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9698x + 87.836
R^2 = 0.981
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.0355x + 9.7631
R^2 = 0.7827
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date


:Young
:Young
y = 0.7656x + 464.73
R² = 0.726
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.7874x + 1222.5
R² = 0.7042
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.0011x + 578.7
R² = 0.9201
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9704x + 99.761
R² = 0.9769
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.0083x + 11.976
R² = 0.8234
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP

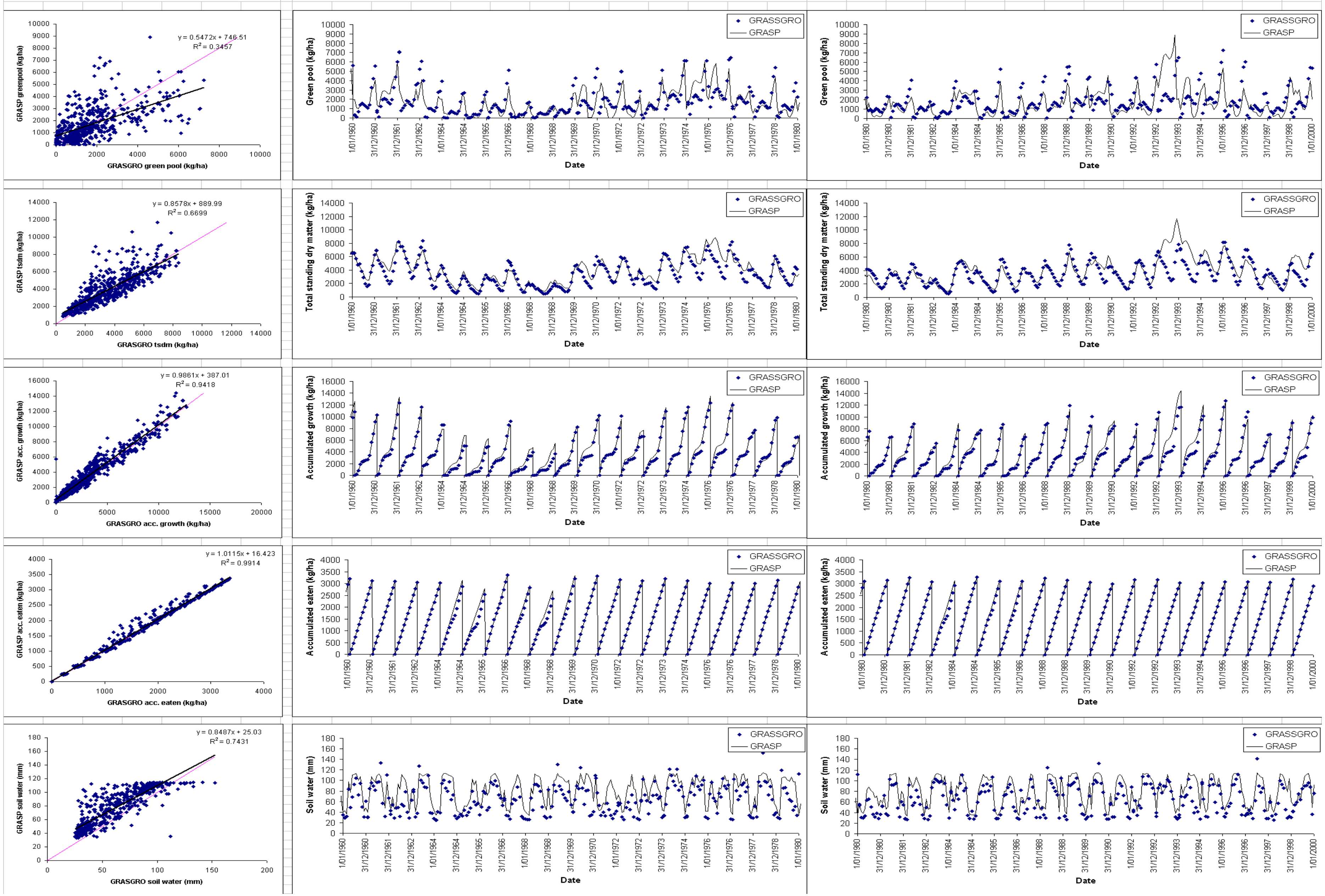

:Binal
:Binal
y = 0.6924x + 510.77
R^2 = 0.6906
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.7526x + 1258.7
R^2 = 0.7142
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.9251x + 240.73
R^2 = 0.9358
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9705x + 84.203
R^2 = 0.9864
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.2878x - 29.415
R^2 = 0.7347
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
GRASSGRO
GRASP
Date


:Crookw
:Crookw
y = 0.5852x + 534.07
R² = 0.5086
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.7552x + 645.77
R² = 0.6641
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.8711x + 133.67
R² = 0.9319
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9836x + 22.743
R² = 0.9956
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.8245x + 24.294
R² = 0.7769
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

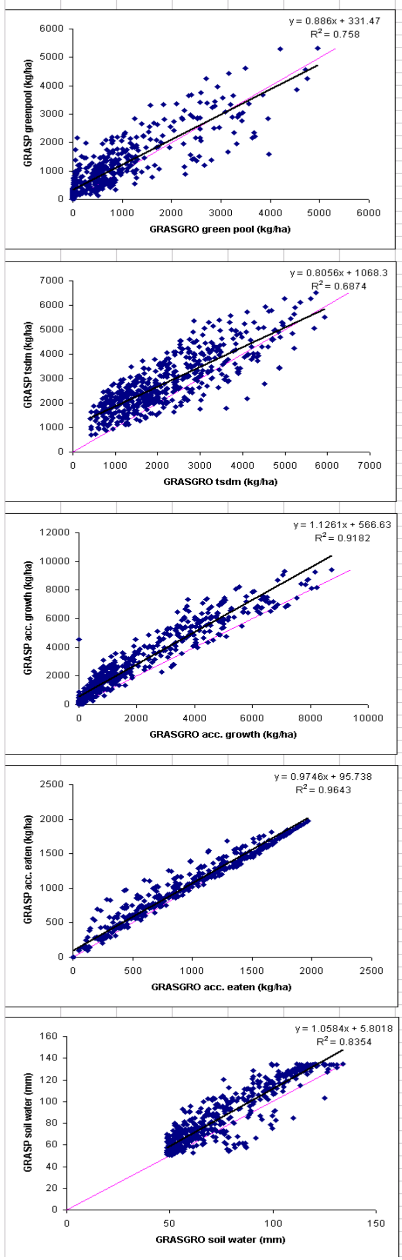

:Echuca
:Echuca
y = 0.9471x + 311.88
R² = 0.8024
GRASP greenpool (kg/ha)
GRASSGRO green pool (kg/ha)
y = 0.842x + 1093
R² = 0.7075
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.1907x + 590.23
R² = 0.9316
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9797x + 93.691
R² = 0.957
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.0598x + 6.2135
R² = 0.8491
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date


:Gundag
:Gundag
y = 0.7722x + 396.17
R² = 0.8058
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.8297x + 769.44
R² = 0.7878
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.993x + 420.92
R² = 0.9428
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9708x + 69.059
R² = 0.9932
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.0861x - 4.01
R² = 0.7189
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

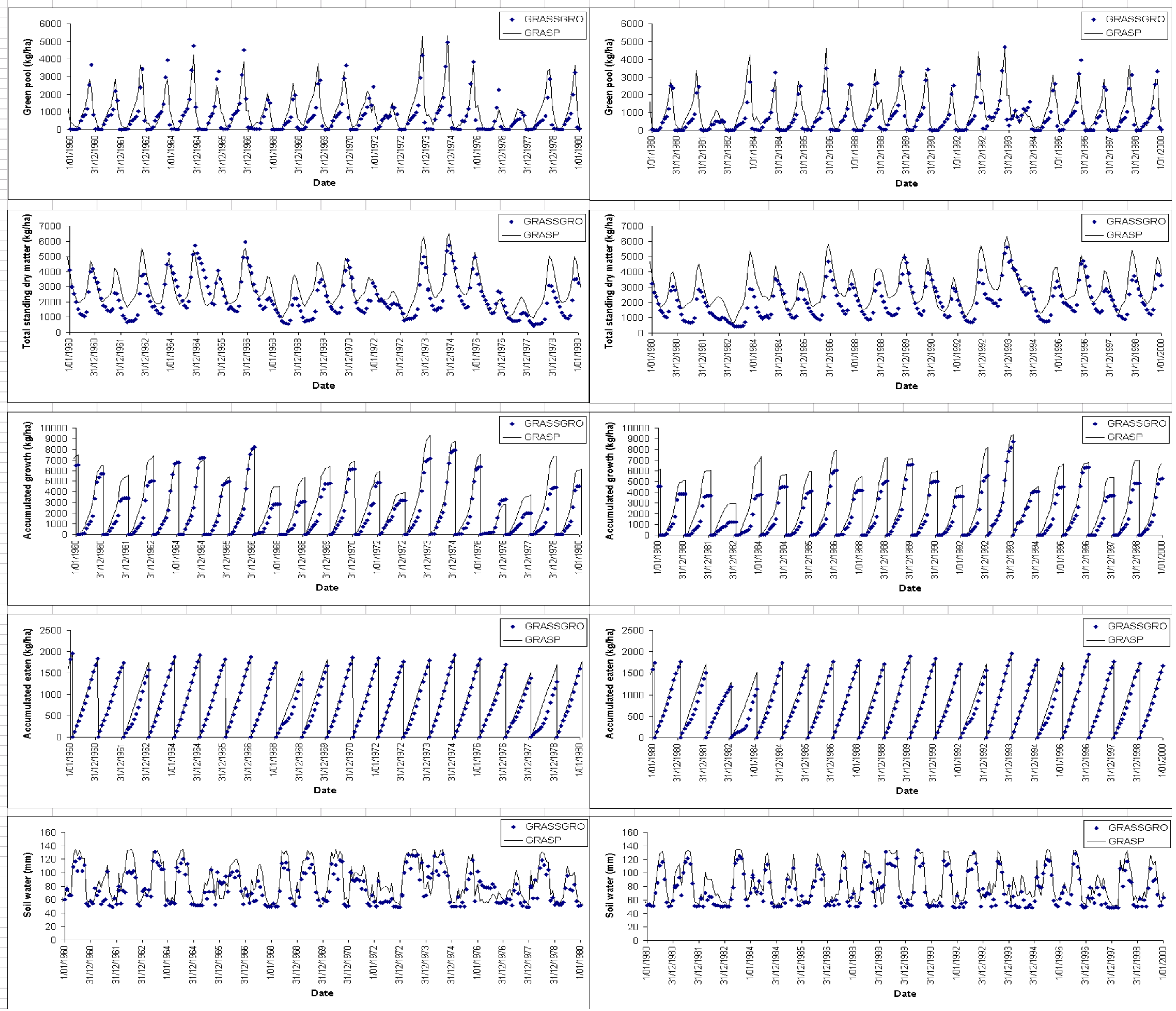
:Nimmit

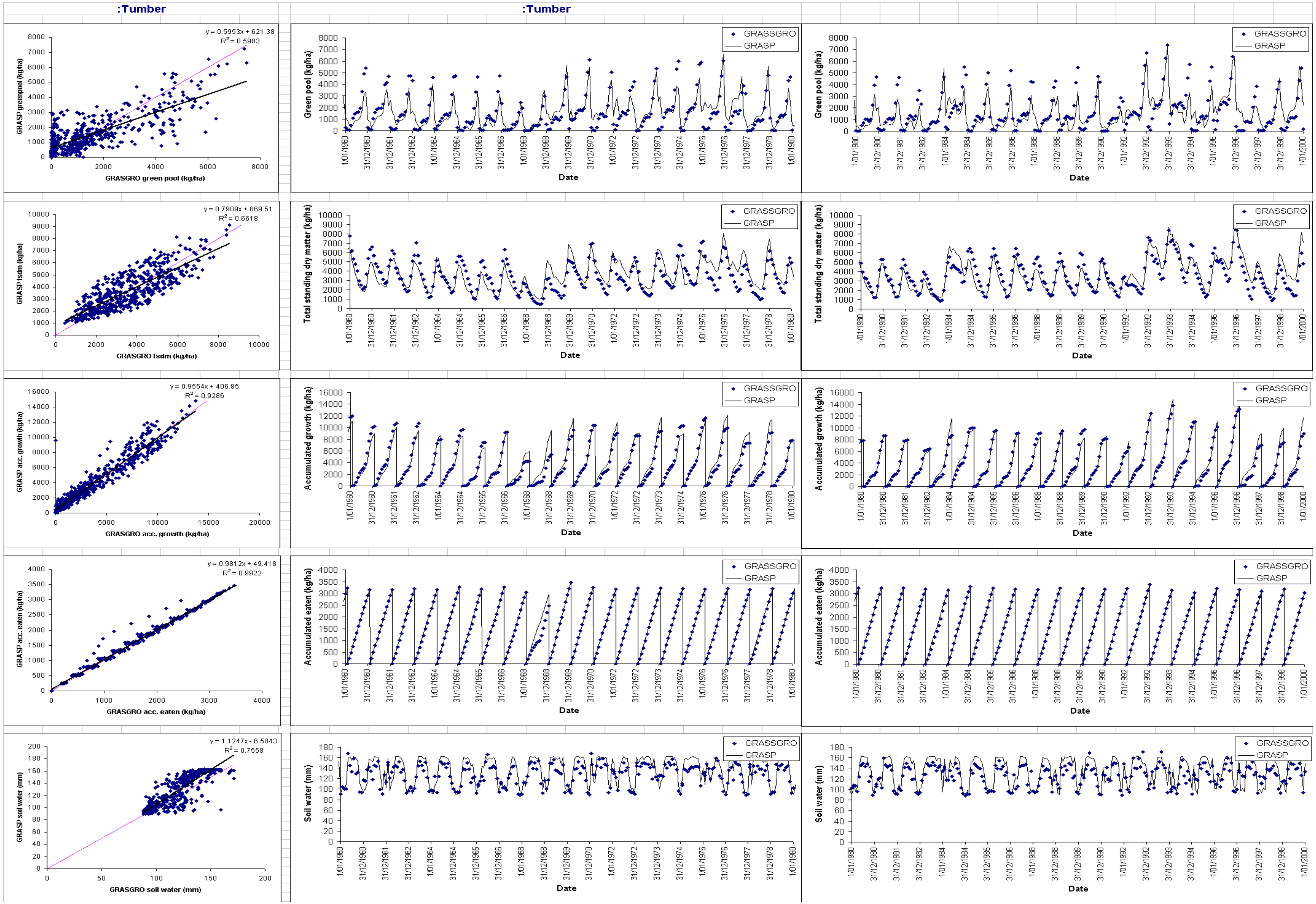

:Nimmit
y = 0.5472x + 746.51
R² = 0.3457
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.8578x + 889.99
R² = 0.6699
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.9861x + 387.01
R² = 0.9418
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 1.0115x + 16.423
R² = 0.9914
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.8487x + 25.03
R² = 0.7431
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP

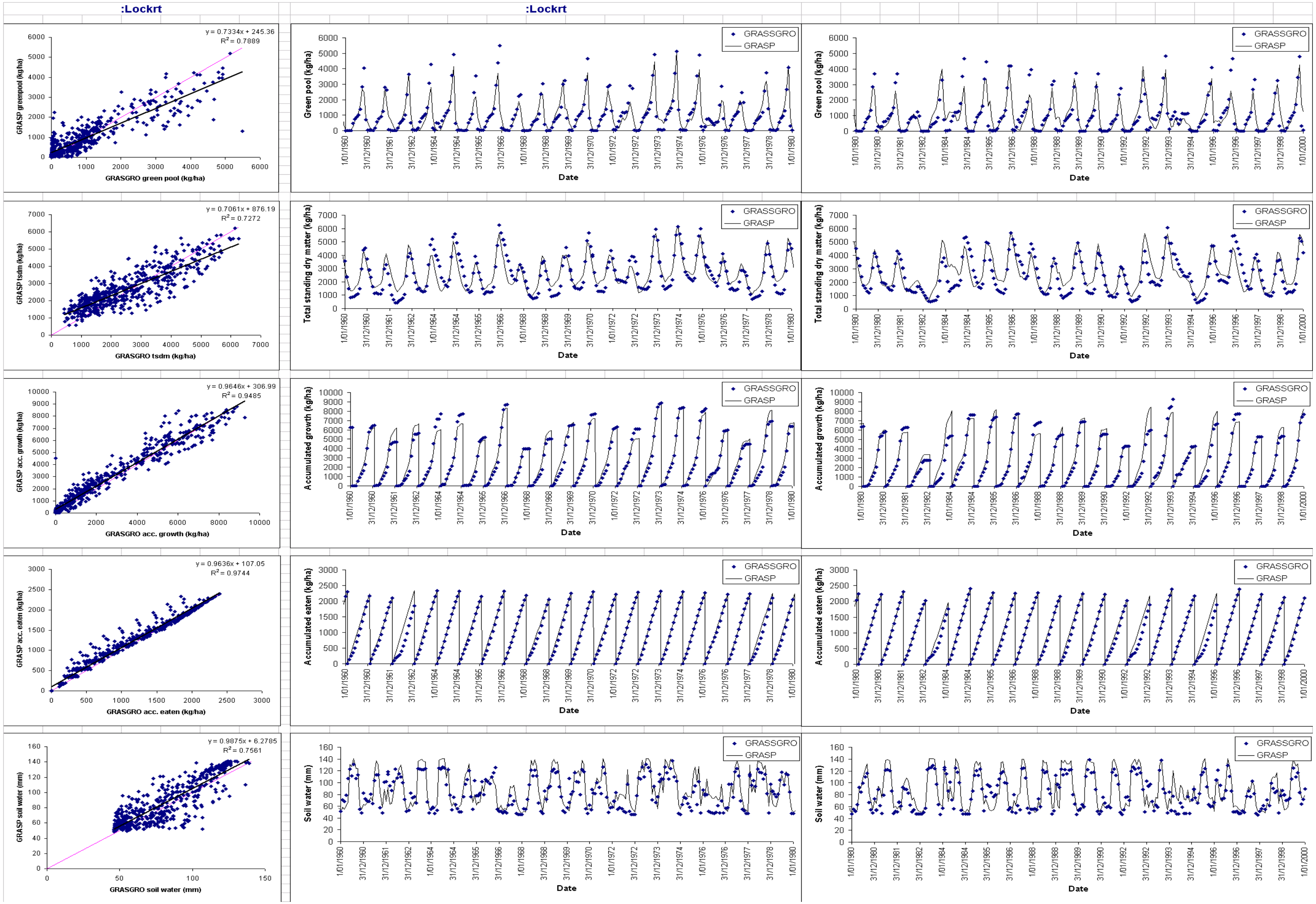
:Tocumw

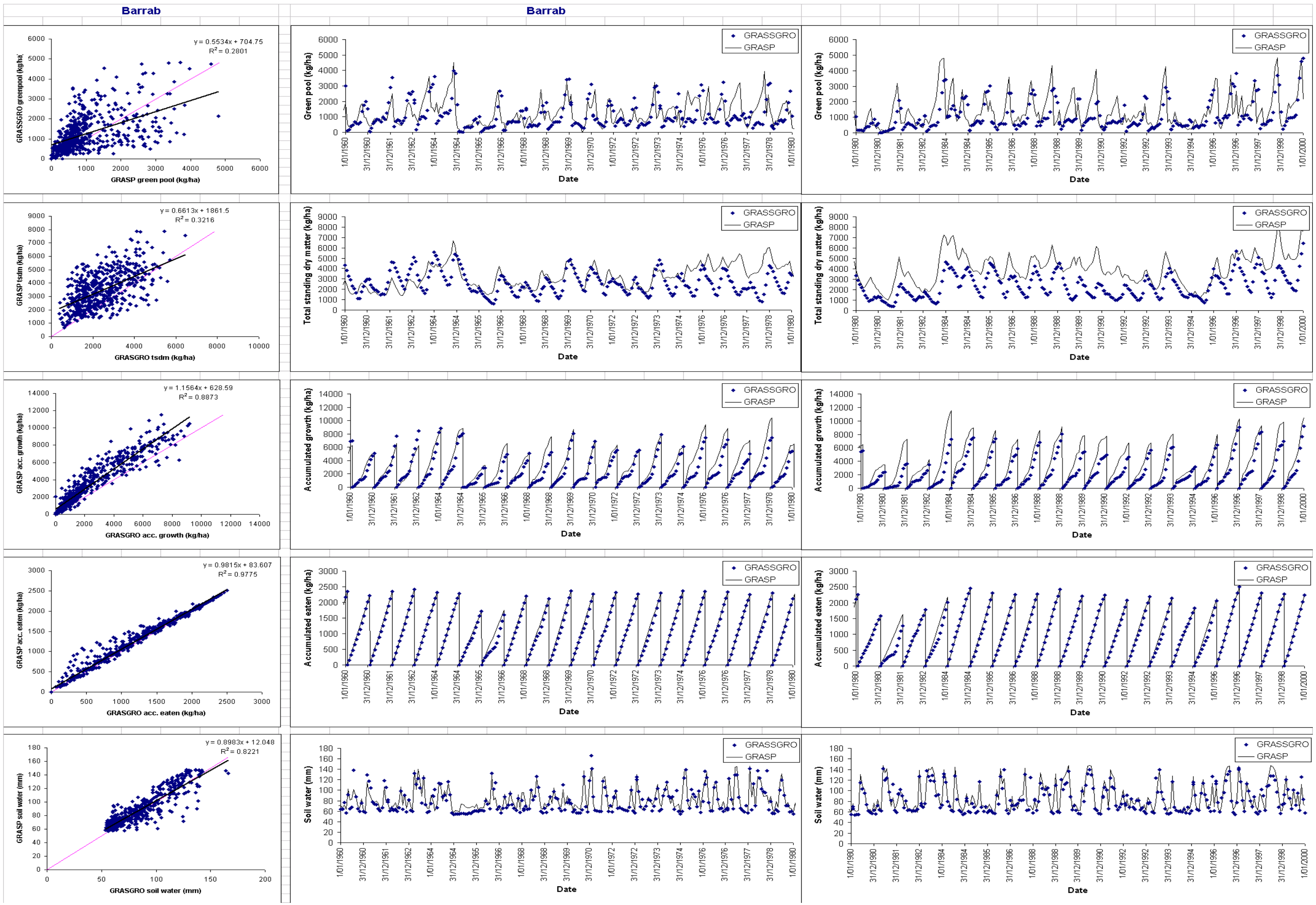


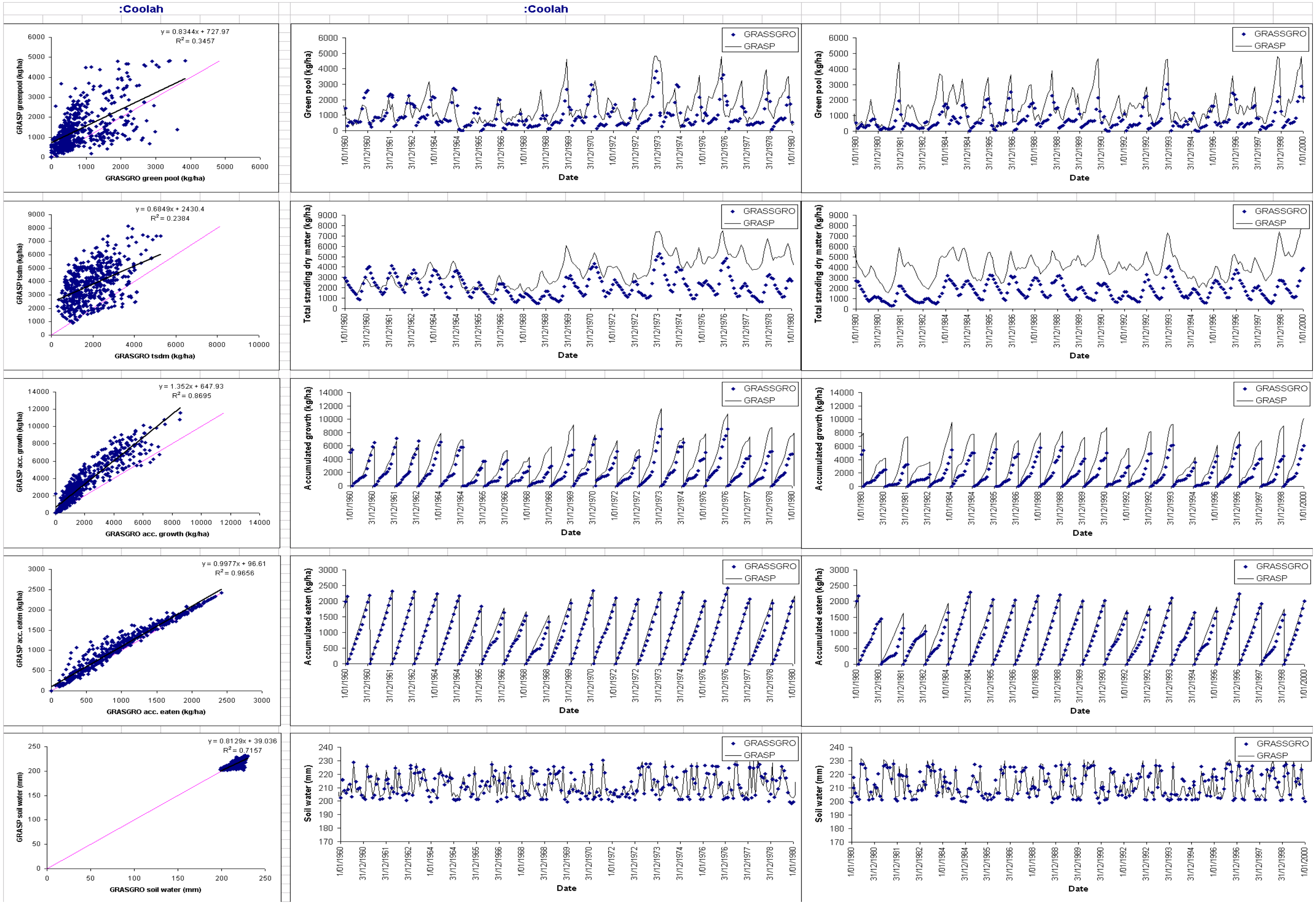
:Tocumw

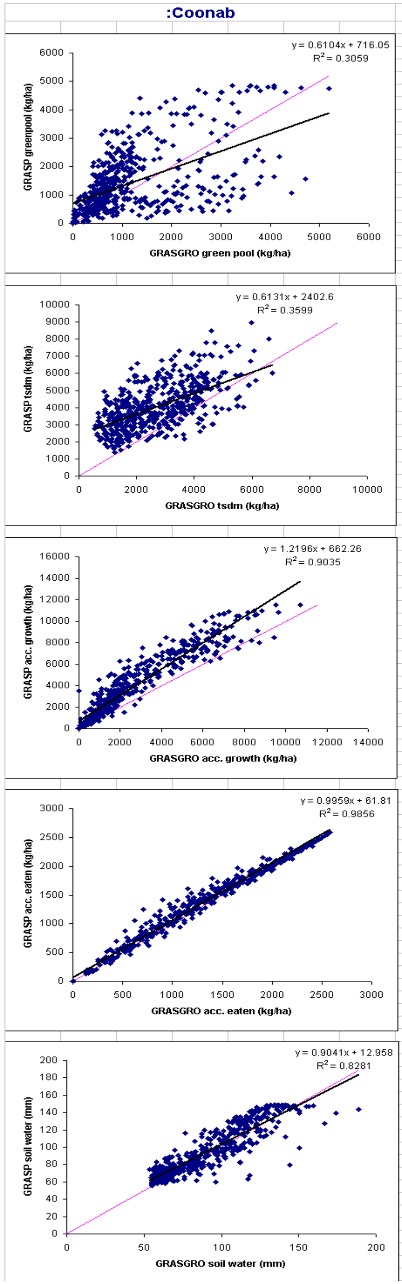


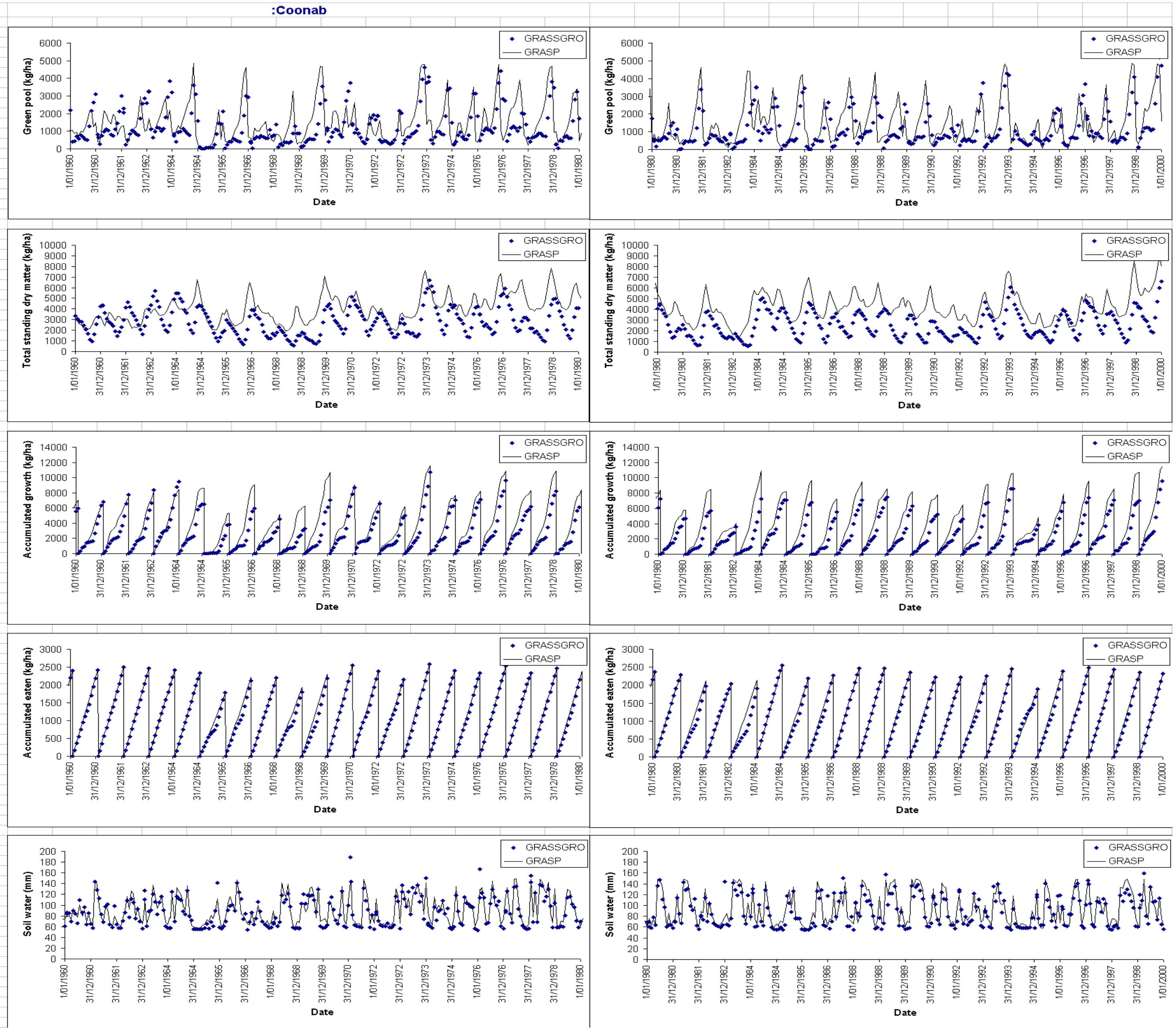

:Tumber
:Tumber
y = 0.5953x + 621.38
R² = 0.5983
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.7909x + 869.51
R² = 0.6618
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.9554x + 406.85
R² = 0.9286
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9812x + 49.418
R² = 0.9922
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 1.1247x - 6.5843
R² = 0.7558
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date

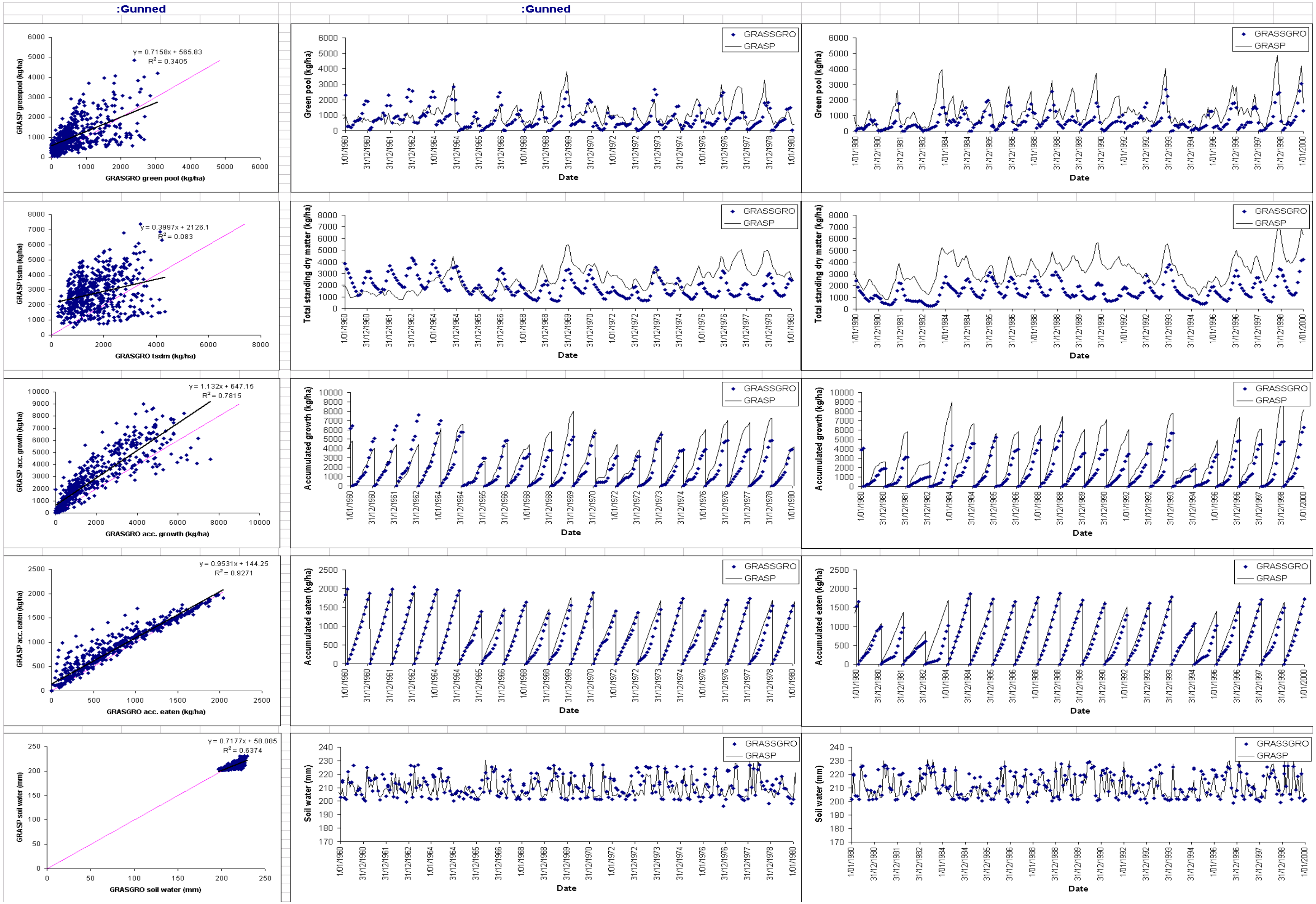

:Lockrt
:Lockrt
y = 0.7334x + 245.36
R^2 = 0.7889
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.7061x + 876.19
R^2 = 0.7272
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 0.9646x + 306.99
R^2 = 0.9485
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9636x + 107.05
R^2 = 0.9744
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9875x + 6.2785
R^2 = 0.7561
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP


Barrab
Barrab
y = 0.5534x + 704.75
R^2 = 0.2801
GRASSGRO greenpool (kg/ha)
GRASP green pool (kg/ha)
y = 0.6613x + 1861.5
R^2 = 0.3216
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.1564x + 628.59
R^2 = 0.8873
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9815x + 83.607
R^2 = 0.9775
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.8983x + 12.048
R^2 = 0.8221
GRASP soil water (mm)
GRASGRO soil water (mm)
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date


:Coolah
:Coolah
y = 0.8344x + 727.97
R^2 = 0.3457
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.6849x + 2430.4
R^2 = 0.2384
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.352x + 647.93
R^2 = 0.8695
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9977x + 96.61
R^2 = 0.9656
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.8129x + 39.036
R^2 = 0.7157
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP


:Coonab
y = 0.6104x + 716.05
R^2 = 0.3059
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.6131x + 2402.6
R^2 = 0.3599
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.2196x + 662.26
R^2 = 0.9035
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9959x + 61.81
R^2 = 0.9856
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.9041x + 12.958
R^2 = 0.8281
GRASP soil water (mm)
GRASGRO soil water (mm)


:Coonab
GRASSGRO
GRASP
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date


:Gunned
:Gunned
y = 0.7158x + 565.83
R² = 0.3405
GRASP greenpool (kg/ha)
GRASGRO green pool (kg/ha)
y = 0.3997x + 2126.1
R² = 0.083
GRASP tsdm (kg/ha)
GRASGRO tsdm (kg/ha)
y = 1.132x + 647.15
R² = 0.7815
GRASP acc. growth (kg/ha)
GRASGRO acc. growth (kg/ha)
y = 0.9531x + 144.25
R² = 0.9271
GRASP acc. eaten (kg/ha)
GRASGRO acc. eaten (kg/ha)
y = 0.7177x + 58.085
R² = 0.6374
GRASP soil water (mm)
GRASGRO soil water (mm)
Green pool (kg/ha)
Total standing dry matter (kg/ha)
Accumulated growth (kg/ha)
Accumulated eaten (kg/ha)
Soil water (mm)
Date
GRASSGRO
GRASP