III.3.4.(II) Designing and Selecting Weather Related Tactical Applications for Agricultural Management and Increasing Their Efficiencies: Multiple Cropping

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Section III.2.4.(II) started with the observation that sustainable agricultural production needs activities which provide information aimed at helping tactical decision makers apply weather and climate information to minimize negative consequences of adverse weather and to take advantage of favorable weather conditions. Most of what was said in that section applies to multiple cropping systems also, and we will therefore deal here with particularities that need to be considered when it comes to the adoption and practice of multiple cropping where tactical decisions are concerned. Walker et al. (2011) have some recent and older literature details.

Agroforestry intercropping with its particular protective and productive associations (Huxley 1983; Reifsnyder and Darnhofer 1989; Ong and Huxley 1996; Baldy and Stigter 1997; Stigter et al. 2002, 2005, 2007) is mainly included in Chap. III.5 of this book, on non-forest trees, but to the crops grown among the trees, many of the aspects below also apply. For pros and cons see Box III.3.16. For success of tactical measures see Box III.3.17.

Box III.3.16 (Contributed by Kees Stigter)

The following review is based on Kinama et al. (2007), where also more references can be found. Tree planting is used, particularly with agroforestry systems (e.g. Garrity 1996), in water erosion reduction, often combined with other soil cover. However, major disappointments with alley cropping in the semi-arid tropics and elsewhere have already led to a greater emphasis on (i) sequential systems, such as improved fallows, which segregate trees and crops in order to remove the undesirable competitive effects of trees (Buresh and Cooper 1999) and (ii) scattered trees with root pruning (e.g. Stigter et al. 2004). Scattered trees as a strategy have been reported to generally influence

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crops positively (e.g. Ong and Leakey 1999), but for other agroforestry systems the results are tactically not always that positive.

Mungai et al. (1996, 2001) showed that for flat land without fertilizers, yield increases due to tactical mulch incorporation in semi-arid Kenya were insufficient for cases where maize rows were strategically replaced by trees. Below a threshold rainfall, yields were even less than those in the controls (Mungai et al. 2001). Evidence of alley cropping in the semi-arid tropics of India has consistently shown a considerable reduction in crop yield, of 30–90%, when the alley width was less than 5 m (Singh et al. 1989). Subsequent research showed that competition for moisture between the roots of trees and crops was responsible for restricting crop growth in the alleys in semi-arid India and Kenya (Ong et al. 1996; Umaya et al. 1999).

Subsequent studies at Machakos showed that there was also little complementarity in the use of light and water between *L. leucocephala* and maize (e.g. Howard et al. 1995). Such findings are not confined to alley cropping systems (e.g. Rao et al. 1998; Ong et al. 2000). Root pruning, mulching and minimum tillage, as weather related tactics, improve this situation in ageing systems (Oteng'i et al. 2007a, b), while also adapted spacing may be applied. See for details Box III.3.17. Such studies confirm that the nature and extent of the interactions between trees and crops change greatly as the system matures (Ong et al. 2000; Oteng'i et al. 2007a, b). They also show that the intensity of these interactions depends on the prevailing environmental and management conditions, particularly seasonal rainfall and the tactical management of its effectivity.

Box III.3.17 (Contributed by Kees Stigter)

The following is from Oteng'i et al. (2007b), detailing tactics of root pruning, mulching and minimum tillage in an ageing agroforestry demonstration plot under the TTMI-project. Hedged agroforestry (AF) demonstration plots with maize/bean intercrops were studied at Matanya in Laikipia district, Kenya, between 1991 and 1995 inclusive, to understand crop yield behaviour due to selected soil moisture conservation methods applicable in semi-arid areas. The treatments were: *Grevillea robusta* trees root pruned, compared to unpruned, both in combination with (1) minimum tillage and mulching with 3 t/ha maize stalks harvested from the plots with additional stalks collected from the nearby farms, and (2) the locally applied method of deep tillage practised by the immigrants from wetter regions, acting as the control. Results showed that: (i) plots with root pruned *Grevillea robusta* trees that were mulched and minimum tilled had most soil moisture available in the shallower layers, during the wettest and the driest season on which this paper is based; (ii) the variation of soil moisture with distance from the *Grevillea robusta* trees showed patterns that were quite similar for plots with root pruned trees in the dry and the wet season; (iii) beans had greater seed yields and maize had more (stover) biomass and (only in the wettest season) grain in plots with pruned trees, minimum tilled and mulched, than in other AF plots.

In the wettest season this resulted in identical maize yields but lower bean seed yields compared to those in the mulched and sometimes also the local control plots without trees. In the driest season bean yields remained the same but maize biomass yields improved above the control yields for the most successful agroforestry intervention applied and (iv) competition between the 6 year old *Grevillea robusta* trees and the crops was indirectly confirmed to be stronger than in earlier experiments in the same plots. This way the agroforestry demonstration plots were very successful in showing the consequences of the ageing agroforestry system, where the soil moisture conservation measures of pruning and mulching kept their effects. Statistical analysis only weakly confirmed the positive effect of root pruning on reducing competition for soil moisture between crops and trees that was very clearly shown to exist by the physical error analysis (Oteng'i et al. 2007b).

For crop matching and crop selection, according to Bowen and Kratky (1986) successful multiple cropping will depend on detailed (strategical) planning, timely (tactical) planting of each crop, adequate fertilizer at optimal times, effective weed and pest control and efficient harvesting, the latter all being tactical decisions with weather related components. Planning in this case means selection of crop species, water availability, plant populations and spacing, labor requirements throughout the season and tillage requirement, planting time to coincide with the optimal growth periods.

Plant growth characteristics such as canopy structure, rooting depth, formative rate of main and component crops must be different to allow for compatibility as intercrop. For examples and details see also Andrews and Kassam (1976), Beets (1982), Baldy and Stigter (1997). The main crop and composite crop must have differing spatial and temporal use of environmental resources such as radiation, water and nutrients (e.g. Willey 1990). Spatial arrangements of plants, planting rates, plant architecture and maturity dates must be considered when planning intercrops (e.g. Papendick et al. 1976; Francis 1986; Baldy and Stigter 1997). General tropical crop knowledge is also necessary (e.g. Squire 1990; Norman et al. 1995; Ong and Huxley 1996).

As to spatial cropping arrangement (e.g. Baldy and Stigter 1997), possible variations are growing two or more crops at the same time with at least one crop planted in rows, growing two or more crops together in no distinct row arrangement and planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting. Others are growing two or more crops together in strips wide enough to permit separate crop production using machines but close enough to allow crops to interact and tree/pasture/livestock systems. Plant density of component crops need to be optimized by adjusting the seeding rate below its full or sole crop rate. The seeding rate depends on the preference of the farmer as to which crop is the major crop and which ones are the intercrop and the economic importance of each crop (e.g. Willey 1985). The problem now is how much reductions will give a very good yield?

The already mentioned literature as well as Stigter and Baldy (1993) also show that planting intercrops that feature staggered maturity dates or development periods take advantage of variations in peak resource demands for nutrients, water, and sunlight. Having one crop mature before its companion crop lessens the competition between the two crops. Using information about planting dates, lengths of the growing period and days to crop maturity, crops suitable for relay cropping and other multiple cropping systems can be selected. Allowing one member of the mix to capture sunlight that would not otherwise be available to the others is another aspect. Planting should be arranged so that there is least interference and competition among crops.

Under field conditions, crop growth is dependent on the ability of the canopy to intercept incoming (solar) radiation, which is a function of the leaf area index (LAI) and canopy architecture, and convert it into new biomass. This then relates to options for the planting pattern of selected crop mixtures, such as both crops in the same row, in alternate rows, in alternate double rows, row orientation e.g. north – south and east – west. Any of the options chosen has implications for resource sharing and yield. All these factors put together form a tactical management tool for intercropping systems. Planning for fertilization should answer questions like where the source of fertilization will be. Will it be from a companion crop or from an external (inorganic) source?

As to pests and diseases control, insect pest populations are often lower when two or more crops are grown together. Some intercropping combinations have been shown to reduce the incidence or severity of pest and diseases attack compared with sole cropping (Altieri and Liebman 1986). See also Box III.3.15 of Sect. III.3.4.(I). Pesticide Action Network (PAN) in Indonesia conducts research into Alternative Pest Control (APC) in both upland and lowland crop combinations. APC involves primarily symbiotic and mutually beneficial combinations of plants e.g. cabbage/celery, carrot/leek, carrot/onion, garlic/potatoes, green bean/potatoes (Tjahjadi 1991).

For soil fertility improvement, leguminous crops sown as main crop or intercrop add to the fertility of the soil (e.g. Walker et al. 2011). In Swaziland small-scale farmers are encouraged to sow maize with groundnut in preference to the sugar bean/maize mixture as maize/groundnut mix proves to be a superior companion crop to a sugar bean/maize mix (Thwala and Ossom 2004). According to Long Li et al. (2007), maize intercropped with faba bean (*Vicia faba L.*) yielded 43 and 26% more respectively. Maize yield increase was as a result of phosphorus uptake mobilised by the acidification of the rhizosphere via faba bean root release of organic acids and other materials. The faba bean yield increase was due to differences in growth and rooting depth.

In Cantarranas, the adoption of velvet bean (*Mucuna pruriens*), which can fix up to 150 kg N/ha as well as produce 35 t of organic matter per year, has tripled maize yields to 2,500 kg ha^{-1}. Labor requirements for weeding have been cut by 75% and herbicides eliminated entirely. The focus on village extensionists was not only more efficient and less costly than using professional extensionists, it also helped to build local capacity and provide crucial leadership experience (Bunch 1987).

In summary, it is necessary to tactically ensure that competition among the different components of the system is not great enough to affect the total productivity of the system adversely (e.g. Walker et al. 2011) or is optimized under seriously limiting conditions (Oteng'i et al. 2007b). Water, nutrients and light are the factors most commonly in short supply. Water use should not be equal in competitive ability, nutrients use or need should vary.

The tactical climate element of multiple cropping is in a more complicated way than for sole cropping also about moisture availability and timing, suitable climate conditions for the growth and development of particular crops, selection of suitable crops and maximizing the use of climate and other resources that affect growth (light, water, nutrients). Others are again tactical climatic determinants of planting densities, choice of multiple cropping systems and timely advice on farming operations (weeding, spraying, pest management, harvesting and drying), again more complex versions of sole cropping requirements and determinations.

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