Comments on LIVESTOCK, LAND USE AND AGRICULTURAL INTENSIFICATION IN SUB-SAHARAN AFRICA

Ralph von Kaufmann and Barry Shapiro

This is an important and timely paper. Bourn and Wint provide highly generalisable, empirical evidence that the concentrations of livestock across the Sahel and the adjacent agro-ecological zones are closely related to cropping intensity and population density. This should make it easier to understand development conundrums such as why grazing reserves, set aside for the exclusive use of pastoralists, have had so little acceptance by the intended beneficiaries. Clearly the pastoralists do not want to be far away from farmers' fields and markets. The correlation between cultivation and livestock suggests that livestock and crop development can and do go hand-in-hand. More importantly, the further evidence Bourn and Wint provide from Nigeria, on the widespread use of animal traction and livestock fattening, supports the belief that population density and crop intensification are not only related to increased livestock numbers, but also to livestock intensification in mixed farming systems.

The human population pressure behind both crop and livestock intensification has important implications for livestock research and development. These findings refute the assumption that although growing population pressure on land inevitably results in competition between crops and livestock for farm resources, it must necessarily lead to replacement of one by the other, or specialization. However, it should not be assumed that the close association between cropping and livestock husbandry means that the activities are well integrated; integration may be limited, even at the family level (Kjenstad 1990). The most important role of livestock for cultivators may be as an inflation-proof store for cash surpluses. Indeed it is difficult to identify any other such investment opportunity available to smallholders. This suggests that food crop security is the principal concern of smallholders at low levels of intensification of mixed-farming systems. The primacy of securing sufficient food grain is demonstrated by the sale of livestock to purchase inputs for cropping or to buy staple grains. The stability of the livestock production, even for pastoralists is, therefore, very dependent on market access that will ensure appropriate grain-livestock price ratios seasonally and at times of drought. Thus the role of market access in stimulating livestock intensification needs to be clarified.

It is argued (in a forthcoming book on *The Economics of Agricultural Technology in Semi-Arid Sub-Saharan Africa* by Sanders, Shapiro and Ramaswamy, to be published next year by John Hopkins University Press) that once the pressure on land increases, necessitating crop intensification with higher levels of purchased inputs, livestock activities such as fattening must also be intensified with purchased inputs. Otherwise, in the face of increased land scarcity and resource competition between crops and livestock, low input livestock systems are likely to disappear. The evidence provided by Sanders *et al.*, based on farm-level case studies from across the semi-arid and sub-humid regions of sub-Saharan Africa, is reinforced by the broad-based empirical evidence reported by Bourn and Wint. If their dataset includes information on the use of inputs, it would be useful to determine whether or not input use in livestock fattening in Nigeria increases with increasing population density.

Even if livestock intensification is driven by the same forces as crop intensification, and is occurring autonomously, it does not follow that the development process should be left to its own devices. Bourn and Wint's evidence on the spread of animal traction in Nigeria demonstrates the efficacy of research and development efforts. The long process of diffusion of traction technology is consistent with the key role that increasing population pressure plays in the adoption of all forms of intensification. It does not refute the need for devoting resources to research and development.

Although farmers are willing to innovate, the changes in feeding, management and breeding strategies they are able to develop endogenously often have only marginal effects on productivity. The autonomous process of integration (Boserup 1965) will lead farmers to take advantage of available technology, but it is only through scientific endeavour that the technology is available in the first place (Ruttan 1982). The impact of artificial insemination and rinderpest vaccines are just two of many examples of the dramatic effect of research on development. As the exogenous forces of growing population and increasing market opportunities create further demand for intensification, research and development efforts can be expected to bring about more rapid technological advances in livestock and crop agriculture.

Development is a disequilibrium condition which, together with market failures, can have harmful consequences for both disadvantaged segments of society and the environment. Along with the impoverishment of disenfranchised pastoralists, Gass and Sumberg (1993) recently commented on the harmful environmental effects of a shift in livestock ownership from pastoralists to urban entrepreneurs who gained control over cattle during the droughts of the 1970s and 1980s. They argue that the breakdown of transhumance and the sedentarisation of livestock near population centres by urban-based owners results in overgrazing and land degradation in these locations. Whether livestock ownership by urban-based investors actually leads to land degradation or is associated with beneficial intensification processes needs to be empirically determined to identify appropriate policies to preserve the environment and promote equitable development.

There are many opportunities for exploiting potential synergies between cropping and livestock production. For example, there are the mutual benefits to be derived from the incorporation of forage legumes and multi-purpose trees into mixed-farming systems. The leguminous forage and browse species have a lot to contribute to improving the yield sustaining capacity of African soils and trials have confirmed their value as feed. Building on the wide-area approach adopted by Bourn and Wint, it would be helpful if regional and national planners could be made more aware of the technologies available for adoption by smallholders. ILCA, in collaboration with the FAO and the International Institute for Applied Systems Analysis (IIASA) is using agro-ecological zones modelling to assess the potential impact on human support capacity of the introduction of forage legumes in smallholder cropping systems in seventeen West African countries. A report is expected in the new year that will indicate ways of working with the trends identified by Bourn and Wint, to match food production with the demands of burgeoning populations. More of such information would be helpful to regional and national planners.

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Mary Tiffen

This is an important paper, providing statistical support to the Boserup hypothesis on the relationship of increasing population density and agricultural intensification in respect to livestock. The fact that domestic livestock numbers increase with house numbers should not come as a surprise. It accords with the findings of recent long-term case studies and with the OECD (1994) West Africa Long Term Perspective Study. The latter found that the productivity of rural population groups was directly proportional to their proximity to markets, which was in turn linked to population density. I would like first to make some points about the way management changes as livestock density increases, and then to comment on distribution.

Livestock management

Carrying capacity and management

The implication of Bourn and Wint's paper is that carrying capacity depends on the management system, not on rainfall. More livestock can be kept on smaller areas of land, and/or on land of poorer natural potential in terms of rainfall and soils, if there is an increase of labour and investment into the feeding and watering systems. In similar climatic zones (500-1000 mm rainfall a year) livestock can be managed under a pastoralist system (appropriate where population density is low, commercialisation difficult and labour and capital scarce); under ranches, (where labour remains scarce but capital for fencing systems and water points is more readily available); under agro-pastoralism, in which subsistence cropping near a fixed home is combined with extensive management of livestock over a large area, or in commercialised mixed farming systems in which animals on private enclosures are fed by a combination of grazing and crop residues, or, at a further stage of intensity, animals are tied or penned, and fed with crop residues and cut (and often grown) fodder. The process of change has been described for Machakos District, Kenya, in a paper for the sister network by Tiffen *et al*. 1993 (see also Tiffen *et al*. 1994).

In Machakos the climate and the ethnicity of the people remains as in the 1930s. Older farmers can tell how management has changed, due to increased land scarcity and new market opportunities. The cattle complex ascribed to them in the 1930s was the result of circumstance, and not a permanent ethnic trait. Morton makes the same point in regard to western Sudan (Morton 1994).

The variations in livestock keeping methods according to resources personally available is clear from table 1 below. One can calculate a range of 3.5 to 0.7 LU ha^{-1} owned (cropped and uncropped together) from the smallest sized farms to the largest ones. The source (Rukandema *et al*. 1980) does not detail management methods, but clearly small and large landowners must use different strategies, and the livestock productivity of the smallest farms is surprisingly high. Mwala is a district of Machakos, averaging 700-800 mm rainfall per year, divided over two growing seasons.

Table 1. Livestock strategies by farm size in Mwala, 1980

Size quartile:	1	2	3	4
Farm size (ha)	1.30	3.24	7.54	17.8
Cropped area (ha)	1.02	1.62	1.92	3.24
Cattle owned	4	5	8	11
Shoats owned	7	12	16	16
% farm cash from livestock	57	60	78	66
Livestock cash income (Ksh)	362	278	688	471

Source: Rukandema *et al*. (1981) and own observations

Changing methods of risk management

As the erratic climate has not changed, owners still risk serious livestock loss after a sequence of severe droughts. After the 1983-4 droughts, farmers in southern Machakos may have lost as many as half their animals, but this was proportionately less than the neighbouring pure stock-raising Maasai on group ranches, due to the more intensive management and the availability of crop residues (Mukhebi *et al*. 1991).

In 1985 a district wide survey of 2000 rural households (ADEC 1985) asked livestock owners about their strategies in the drought year. Results showed that 27% were paying for rights of access to grazing land belonging to others; 26% had purchased in fodder, 20% had collected fodder and transported it to the animals, and 4% had moved their cattle to another area. 17% had made sales as a result of the drought, but less than 2% reported consuming drought-affected animals. Thus, renting in land and purchase of fodder substitute for the pastoral strategy of moving the herds. Use of own crop residues was normal and more than 50% of livestock owners combined grazing with seasonal hand-feeding. Only 31% relied on grazing throughout the year; 6% hand-fed all the year and 10% always tethered their animals.

Changes in tenure

In most African customary systems, tenurial rights are strongest for land cleared for cropping, and rights to such land become more permanent as fallows shorten. The owner then also controls access to crop residues. In some areas it has been observed that people also reserve certain areas of grazing for sole use as land becomes scarcer, investing in fencing and hedging. This land then becomes effectively private property. In other areas, including Machakos, people obtain rights over land by clearing and cropping, but then allow part to revert to grazing, private because once-cropped. In Kenya the state has supported the privatisation of settled land by facilitating legal demarcation of boundaries and registration of title. In areas like Machakos, there is little unclaimed land left, since people who inherited unviable farms often sold up to establish farms in new areas. In the ADEC (1985) survey, only 5% of respondents felt they `had no restriction on grazing areas where feed was available'[1].

We need to think very seriously whether about whether governments should encourage this natural move to private tenure, which Boserup (1965) also noted. Communal management, if it ever truly existed, has its own difficulties. Private tenure does not frustrate opportunistic management; people can rent in land or buy in fodder. Pure pastoralists who may suffer from increasing land privatisation are a minority; the majority are the small mixed farmers who will suffer if they are not allowed full control over the land they legally clear, and who, if they do not have certain title, may not make the investments we would wish to encourage.

1It is not quite clear what this means; it is likely to include large owners of grazing land, since unclaimed land was already scarce in 1985 and common access land was mainly road verges *etc*.).

Supporting natural tendencies

Bourn and Wint conclude by asking whether we should `do nothing, just let it happen'. Morton's study in Sudan shows that bad government can in fact frustrate the natural tendencies towards intensification and commercialisation as population density increases. We should therefore encourage governments to support the natural tendencies, by making trade and information exchange easier and cheaper, by encouraging private investment and the move to private tenure, by not taxing away all incentives, by maintaining law and order and a steady legal framework (see Tiffen *et al.* 1994). Support to rural infrastructure and services, including transport as well as extension and animal health services, can then assist.

Livestock numbers and distribution

Livestock are notoriously difficult to count. One dataset we used in Machakos came from low-level aerial reconnaissance in 1981 (Ecosystems/Norton-Griffiths 1982) but unfortunately was not combined, as in the Bourn and Wint report, with ground surveys to determine hidden livestock to roof-top ratios. This led to under-counting, particularly in the areas of highest population density where most animals are tethered or penned, usually under trees.

One also needs to average out not only between wet and dry seasons, but over a run of years that include both the drought and the recovery period. It would be helpful to have a description of the rainfall situation in the Bourn and Wint's seasons of survey. In Machakos the normal counts of the Livestock Department showed a substantial fall in numbers after 1984. By 1989 cattle numbers were above the pre-drought levels, but goat numbers remained lower. There was some evidence that rising prices for milk and fruit tree products had led to farmers building up their cattle again (and often improving the breed), but switching from goats (which are very partial to orange trees!).

It would be of interest to know the size of Bourn and Wint's sampling areas. The admittedly poor quality data from official livestock counts at different points in time in both Machakos District and at an earlier period in Gombe Emirate in Nigeria confirm an increase in numbers as population increased. However, in both cases there may have been a shift of livestock within the district to the less densely inhabited parts, which in Machakos have lower and more erratic rainfall, and in Gombe had more porous soils, and inaccessible groundwater. Table 2 illustrates this with respect to Gombe. It should be noted that the table refers to taxed cattle; many cattle escape taxation and it is quite possible, for example, that the collectors ignored the two or three cattle per household that a farming household may keep for draft and milk, and concentrated only on those with larger herds. This would lead to substantial under-counting in the more populated southern area. It should be explained that many immigrant farmers from other parts of northern Nigeria moved into the southern part during 1950-65, due to the suitability of its soils for profitable cotton farming. They did not go to northern Gombe, further from the market with poorer soils. In the 1920s southern Gombe was mainly tsetse-infested bush, which settlement had almost eliminated by 1963. As human numbers increased more than three times, cattle herds taxed showed a slight decrease, but the table also illustrates that cattle had come under a different management system, being owned by settled farmers rather than by nomadic Fulani as in 1925-6. Nomadic Fulani had had to make a decision either to settle and farm, or to lose their rights to return occasionally to a farming site. Many had chosen to stay, and had become cotton farmers at a settled base. In the poorer north there was still space in 1965 for nomadic owners.

Table 2. Taxed cattle and population in Gombe Emirate

	Cattle 1925-1926	Humans 1931	Cattle 1965-1966	Humans 1963 (1)
Southern Gombe	54,347	89,744	45,711	318,462
(of which nomad)	27,662		3,399	
Northern Gombe	30,806	105,073	61,236	229,676
(of which nomad)	1,398		10,763	
Gombe Town	1,003	3,243	4,106	47,265
Total	86,156	202,989	111,053	595,400

(1) 1963 census figures were inflated. Figures for one of the northern districts are adjusted downwards here in the light of local information. Figures for the remaining districts appear credible.

Source: Tiffen (1976; 147)

In Machakos most of the land with good potential for cropping is now cropped, and more livestock are being kept on poorer land than was the case in the 1930s. However, the total land available to cattle has increased, because settlement has driven back tsetse.

We need, therefore, to carry out more investigations as to where cattle are at the district level and to examine the strategies that enable more livestock to be kept on low potential land. We also need to examine distribution at the farm level. In Machakos there is now a mosaic of grazing and cropped land, as farmers have been able to enclose grazing land relatively near their cropped fields. This makes integration of livestock and cropping (manure, draft, crop-residue use) easy. It is more difficult where the tenure system only gives rights to cropped land, and where with increasing population density cattle are driven outwards, making the carting of manure more expensive.

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J. Sumberg

Central to Bourn and Wint's paper is the argument that important, on-going processes of autonomous intensification can be observed within rural West Africa. These processes are driven by increasing human population density, and characterised by intensification of land use and a closer association between crop cultivation and livestock production. The critical indicator of this increasing integration is a strong positive relationship between cultivation percentage and livestock biomass. Bourn and Wint suggest that these processes of intensification reflect the Boserupian logic of `necessity being the mother of invention'. They conclude the paper with `a plea for wider appreciation and better understanding of the dynamic interactive processes of human population growth, agricultural expansion and environmental change that are occurring throughout the continent'. These are clearly important issues and the authors base their analysis on a massive amount of data, including livestock inventories, land use patterns and human settlement. Before commenting on the central elements of the argument however, two initial observations are warranted.

The first point to note is Bourn and Wint's comment that over the last few years the discussion relating to livestock in Africa has begun to revolve very much around the so-called `new thinking' about rangeland ecology and African pastoral production systems, while considerable numbers of livestock are actually kept in higher rainfall areas by people who are not traditional pastoralists. In a recent paper, Scoones (1994), citing ILCA (1987) and Winrock (1992) indicates that 59% of all ruminant livestock in Africa are found in non-equilibrium environments, and that 51% of cattle, 57% of sheep, 65% of goats and 100% of camels are found in the `arid and semi-arid areas (*i.e*. areas with rainfall below 600 mm)'. These figures certainly appear to justify the focus on non-equilibrium areas: `we are talking of significant areas of land supporting large numbers of pastoral livelihoods and contributing a large amount to national economies' (Scoones 1994: 2).

However, statements of this nature arguably give a distorted view of the importance of non-equilibrium areas. Ellis *et al*. (1993), citing the work of Caughley (1987) suggest that non-equilibrium conditions can be expected where the coefficient of variation (CV) of total annual rainfall is greater than 30%. Furthermore, with reference to work by Coppock (1993), Ellis *et al*. tentatively conclude that `a threshold for non-equilibrium dynamic behaviour may occur between 300-400 mm rainfall *per annum*'. Coppock himself suggests that for East Africa a distinction can be made between `arid systems (having unimodal or weak bimodal delivery of an annual rainfall of < 400 mm) and semi-arid pastoral systems (having a bimodal delivery of 400-800 mm annual rainfall)' (Coppock 1993: 59), with the former generally exhibiting non-equilibrium characteristics, and the latter equilibrium.

Using the <400 mm rainfall threshold places the disequilibrium area in the drier part of the arid zone (defined by Winrock as <500 mm). Similarly, comparison of maps presented by Le Houérou *et al*. (1993) indicate that the isohyet of 30% CV in annual rainfall is closely associated with total annual rainfall of 400-500 mm, again, well within the arid zone. Thus, under the crude assumption that non-equilibrium conditions are found predominately in the arid zone, data presented by Winrock (1992: 23) indicate that while this may include approximately 50% of the land area of East and West Africa, and 36% of land area overall, only 21% of cattle and 30% of all livestock units are associated with these areas. On the other hand, approximately 55% of cattle and 50% of all ruminant livestock appear to be associated with semi-arid and sub-humid areas that are characterised by equilibrium conditions. These estimates contrast with the figures and images evoked by Scoones. Thus, the attempt by Bourn and Wint to re-equilibrate the discussion of livestock in Africa by helping to place the `new thinking' in perspective is certainly welcome.

The second important issue raised by the paper is the proposition that within a given area the goals of agriculturists and pastoralists do not necessarily conflict. Increasing conflict between farmers and herders is cited all too often to justify a wide variety of technical and institutional interventions from fodder banks to pastoral associations and land tenure reform. Significantly however, there are few reliable data to demonstrate either more frequent or more violent conflict, or to suggest that established structures and institutions for resolving disputes have broken down. This is an area that certainly deserves further attention.

In relation to the central argument of the paper, the proposition that patterns of agriculture and livestock production are dynamic and respond to changes in population density (among other things), are certainly not new. However, there have been relatively few long-term studies in West Africa which have demonstrated clearly the relationships between these factors. Unfortunately, the cross sectional approach taken by Bourn and Wint, encompassing a number of sites over a range of agro-ecological zones and over a period of 13 years would itself appear to have severe limitations. This is essentially the same approach taken by Pingali *et al*. (1987) in their study of agricultural mechanisation and McIntire *et al*. (1992) in relation of crop-livestock integration, but it only makes sense if one is willing to believe that the sites are representative of different stages along a single development path. Otherwise, there is no logical basis on which to compare sites or draw conclusions regarding the direction, pace or factors associated with change over time. Given the range of agro-ecological conditions, the assumption of a single development trajectory is simply unjustified. The analysis of large datasets aggregated over such different conditions should not be seen as a replacement for longitudinal studies of change within particular sites.

The authors depend on regression analysis to demonstrate the central relationships between cultivation, habitation and livestock biomass. One is left to assume that cultivation and habitation are themselves strongly correlated, while both increase with increasing rainfall to approximately 1000 mm and decline thereafter (similar to the pattern shown in figure 4). If the relationship between cultivation and livestock density (figure 2) appears straightforward, that of habitation density and livestock (figure 3) is more problematic. With no data between 50 and 130 roof-tops per sq. km, it begins to look like two populations rather than one. In any case, it is important to note that while either of these two variables account for approximately 50% of the observed variation in livestock density, there is no indication of what might account for the other half. The results of the multiple regression model are of limited value because of the problem of (multi)collinearity.

The discussion of animal movements over seasons and agro-ecological zones (figure 5 and table 2) is interesting but ultimately raises more questions than it answers. Bourn and Wint use figure 5 to support the conclusion that while there is little net seasonal movement of livestock biomass below 750 mm and above 1500 mm, livestock biomass increases by 20-30% during the wet season at the `semi-arid/sub-humid interface'. It is postulated that there is a seasonal flux of animals into these areas in the wet season, perhaps accounted for by `the return of transhumant herds'. The problem with this explanation is that there is no indication where these animals are coming from as nowhere along the rainfall continuum is any significant in-migration of stock during the dry season shown. Further confusion is added by table 2, which shows 3-11% lower livestock biomass density in *all* agro-climatic zones in dry season - so, where are the animals going? Clearly part of the problem must be related to the very nature of the dataset as indicated earlier. The fact that some of the study sites such as the Inland Delta in Mali are characterised by low rainfall yet support large numbers of incoming cattle during the dry season can only add confusion to such a broad-brush analysis.

In relation to the suggestion that autonomous, local action has resulted in the control of tsetse, it would certainly be more realistic to see these as contributing to the range of factors - including sustained government and donor supported fly clearing programmes and the role of drought in reducing habitat - that have affected fly populations and ultimately livestock distributions.

Overall, the paper tells us little about the nature or extent of change in rural West Africa. The discussion about the nature and causes of intensification is a discussion about change over time. In this case an aggregated analysis of a mass of data over a very broad set of ecological conditions does little to improve our understanding of these issues.

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Ian Scoones

This is an interesting paper which shows quite categorically what others have been speculating about for some time - that livestock (cattle and goats especially) and settled agriculture increasingly occupy sub-Saharan Africa's semi-arid and sub-humid zones alongside each other. This is demonstrated elegantly by the aerial survey data presented, along with some interesting additions to our understanding of livestock biomass-rainfall relationships and some suggestive conclusions about patterns of intensification.

The paper, however, also raises many questions. Six spring to mind following my reading:

(1) *Have livestock moved onto farms or farms moved to the livestock areas?* The paper concludes that there has been a pattern of intensification on farms in the semi-arid zone, resulting from increased population pressure and the need to adopt a classic mixed farming approach (along the lines suggested by Boserup (1981), McIntire *et al.* (1992) and others). However an alternative scenario could be suggested in which farms move into the livestock areas, either because of resource scarcity or because of the tsetse challenge further south. The livestock observed by the aerial surveys may still be pastoral livestock, but ones now forced to make use of interstitial grazing or adopt practices of `pastoral gardening' (Thebaud 1993). Simple correlations, as the authors acknowledge, do not prove causal connections. But it is the chain of causation that is of interest to policy and needs further examination.

(2) *What are the implications of longer term rainfall changes?* The rainfall isohyets have moved dramatically southwards over the last 20 years in the Sudano-Sahelian zone (although there are some signs of a northwards drift again in the last few years). Once sub-humid areas are now semi-arid and once semi-arid areas are now arid. The impact of this secular trend in rainfall levels is poorly understood, but may lie behind some of the correlations observed. For instance, the data show maximum livestock biomass at the 825 mm mark, but today actual rainfall may be much lower in this region, influencing the relationship between livestock and agricultural production. Thus areas that were previously farming lands are now more suited to livestock rearing, requiring a shift in emphasis. Equally areas that used to support transhumant livestock are now so dry that animals have been forced to move southwards, resulting in a convergence of livestock in the (now) semi-arid zone. From the cross-sectional data presented it is impossible to discern the presence or otherwise of any secular trends and the

dynamics involved. It is also dangerous to compare detailed survey data with Jahnke's data from the 1970s, which are based on data sources almost as unreliable as the Nigerian human population censuses (see the paper). Time series data, combined with detailed historical analyses at particular sites are required to complement the broad-brush continental picture presented here.

(3) *Who owns the livestock?* Aerial surveys tell us nothing about ownership patterns and it is not clear whose livestock are being observed around the village settlements. Do they belong to `farmer herders' or `herder farmers' (Toulmin 1983), transhumant pastoralists or people living in towns? Patterns of ownership will definitely influence the dynamics of intensification. It is not clear whether the trend is towards more mixed farming (as implied by the paper) or whether agricultural-pastoral interactions persist on the basis of various forms of herding, manure and fodder supply contract. There are good reasons to believe that the maintenance of a mobile pastoral sector utilising the dry rangelands to the north will require an integration of agriculture and pastoralism, while still retaining a mobile, transhumant component (Bayer and Waters-Bayer 1994). A major research question to complement the data presented in this paper thus centres on patterns of ownership and associated commitments to different types of production system.

(4) *What are all these animals eating?* The strong correlation between livestock biomass and cultivation levels is striking. As the authors note this is a far stronger relationship than between livestock biomass and rangeland extent or grass cover levels. So what are the high densities of animals living in the semi-arid and sub-humid zones eating? Sustaining livestock within farmed areas requires the combined use of crop residues (which may yield more than rangeland and at more stable levels) and patchy grazing resources, such as low-lying depressions, field boundaries or uncultivated hilly areas. Maintaining high populations of livestock is not impossible, as is shown by the agro-pastoral areas of Zimbabwe (Scoones 1993), but requires careful crop residue management, flexible localised movement and patch resource use. Access to such resources is therefore vital and resource tenure issues are put centre stage. The question then is not only who owns the livestock, but who owns or controls the fodder resources.

(5) *What patterns of livestock movement are occurring?* The data presented in the paper are equivocal about whether patterns of livestock movement continue to occur. It appears that most cross-zone movement occurs in what is defined as the 750-1250 mm zone reflecting seasonal movements of transhumant herds. The apparent absence of seasonal movement in other areas is suggested as evidence of a process of sedentarisation. However, this conclusion may need to be tempered somewhat. First, the data sources are probably inadequate to reach firm

conclusions, as most wet and dry season surveys at the same site appear to be in different years (table 1). Second, with the drift of livestock populations southwards, movements may now be operating on a different scale. The landscape forms and patterns of fodder availability of these zones may be more conducive to localised movement between particular key resource sites with long distance movement only occurring in years of feed scarcity. However such a pattern should not be equated with sedentarisation in a neat mixed farming model, with paddocked or stall fed livestock permanently on the farm. Opportunistic management involving flexible responses and mobility may be just as important for agro-pastoral livestock resident in the dryland farming areas as it has always been in the arid rangelands (Scoones 1994).

(6) *What patterns of intensification are really happening?* In its conclusion, the paper claims that a pattern of autonomous intensification in the farming zone is evident. While it is currently fashionable to invoke Boserupian models this must remain a hypothesis as there are still some poorly addressed problems with the standard mixed farming intensification model. Assuming a particular pathway of intensification thus has attendant dangers. Turner (1993) comments that `the false promise of sedentary mixed farming has indirectly had a negative effect by providing justification for government indifference in defending transhumant corridors from agricultural encroachment, despite the fact that greater livestock mobility has become more necessary in heavily cultivated areas'. Bourn and Wint conclude with a plea for `wider appreciation and better understanding of the dynamic interactive processes of human population growth, agricultural expansion and environmental change'. I could not agree more. But let us keep an open mind as to the trajectories and the processes involved and not be bound by preconceived models of transformation and change. This paper poses many questions; it remains a challenge to empirical research to find out what is really going on.

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Thomas J. Bassett

Bourn and Wint's paper adds nicely to a growing body of literature on livestock raising within the so-called tsetse fly zone of West Africa. The southerly movement of pastoral peoples from the semi-arid to sub-humid zones of West Africa since the 1970s is now well documented (Bassett 1986, 1994; Blench 1985; Boutrais 1986, 1994; Gallais 1979). Bourn and Wint's analysis complements existing studies by highlighting the relationships between the distribution of livestock and human settlement patterns. The strong associations between the presence of livestock, the percentage of land under cultivation, and `density of rural settlement' both confirm and challenge the thrust of recent research on agricultural intensification in Africa. For example, their results confirm the assumed links between the degradation of tsetse fly habitats and the expansion of trypano-sensitive cattle into the sub-humid zone. On the other hand, their findings seem to contradict recent research that shows livestock raising to be declining in areas of high population density. Bourn and Wint suggest that this contradiction is only apparent by arguing that their results are consistent with Boserup's theory of `autonomous intensification' in which population pressure is viewed as an independent force driving agricultural innovation and intensification. This is a plausible interpretation of the data but one that is not adequately supported in their paper.

First, the authors do not persuasively show that agricultural intensification is taking place in the various study areas. Despite frequent references to the `intensification process' and `intensity of land use', Bourn and Wint never define what they mean by these terms. The only indication or `yardstick' of intensification they provide is the spread of animal traction and animal fattening in Nigeria. Yet even these measures are of limited value because they are restricted to data collected for a single year. The authors need to present longitudinal data that show trends in animal traction and fattening over time in order to determine the nature and extent of intensification. Given the lack of reliable demographic and agricultural data in Africa, many authors use alternative indicators like `frequency of cultivation' to measure intensification (see the case studies in Turner *et al.* 1993). Bourn and Wint need to provide a comparable measure to assess trends in agricultural intensification in which livestock are an important component. In the absence of such measures, the reader is unable to determine whether the expansion of livestock raising in farming areas represents a process of intensification or extensification.

Second, too little information is provided on animal husbandry and ownership which makes it difficult to say anything specific about the dynamics of agricultural intensification. What percentage of the animals counted in the various surveys belong to sedentary farmers versus semi-transhumant pastoralists? What percentage are employed as oxen versus fattened for the market? How does ownership relate to the production system? What percentage of animals are stall fed versus grazed on open rangelands? If there has been a notable expansion of a specific livestock raising system then we need more information about the conditions of its intensification.

Third, the use of `density of rural settlement' as a surrogate measure for population density does not indicate actual population levels nor changes in population densities over time. Such data are critical however for substantiating the authors' thesis that increasing population pressure is the principal cause of agricultural intensification. Population data might help to explain, for example, the `bizarre observation' that livestock numbers and percentage of land cultivated are strongly associated. This may be the case under certain population densities but not so under others. Case studies in areas of high population density elsewhere in Africa indicate a decline in livestock raising with increasing frequency of cultivation. Cattle are either stall fed or replaced by small stock (Bernard 1993; Feierman 1993; Ford 1993). Again, longitudinal data showing trends in livestock raising in relation to changing population densities and land use patterns are required. Recent research undertaken by Mortimore (1993) in the Kano close-settled zone of Nigeria and that of McC Netting *et al*. (1993) among the Kofyar on the Jos Plateau present a clearer and more complex picture of the relationship between population pressure and agricultural intensification. What these studies show is that agricultural intensification (characterized by crop rotation, reduced fallowing, and new technologies) is driven as much by market forces as by population growth.

McC Netting *et al*.'s study is interesting in that historically both population pressure and market incentives have played important roles in Kofyar agricultural intensification. During the pre-colonial period, relative scarcity of land and high population densities induced an intensification of agriculture along Boserupian lines. The Kofyar moved from the Jos Plateau during the colonial period to practice a more extensive system of cultivation in the lowland frontier zone. Over the past few decades, the highlands have experienced a `dis-intensification while the lowland farming areas have become increasingly intensified. Incentives such as good access to markets, attractive crop prices, off-farm incomes, and effective soil and water conservation techniques have been essential to this recent intensification of lowland farms.

Fourth, considering the critical role played by market forces in the southerly expansion of cattle in Nigeria (Blench 1994), Bourn and Wint's policy-oriented questions strike me as too simplistic. They ask `if that process [agricultural intensification] is an inevitable consequence of population growth, why should agricultural and livestock development be actively pursued? What is to be gained from promoting the inevitable?' Following Turner *et al*. (1993), I would argue that agricultural intensification does not inevitably follow from population pressure on resources. The extent to which population is an independent driving force of intensification or is synergistic with other forces is an empirical problem that is most fruitfully examined at a case by case level. Given that population growth can lead to either agricultural intensification or stagnation, we need to know more about those conditions that lead to more positive outcomes. If favourable economic conditions are important for agricultural intensification, then one needs to consider the policy implications of these economic transitions. In northern Côte d'Ivoire, for example, the impressive expansion of oxen since the mid-1970s has been linked to farmer access to credit in the context of the government's subsidized cotton development program. The growth of mixed farming has also been contingent upon the availability of animals provided by immigrant Fulani herd owners who have been attracted to the country by a variety of economic incentives. In summary, agricultural intensification as measured by the expansion of animal traction has not been an `autonomous' process but one that has been strongly influenced by a succession of colonial and post-colonial rural development programs under changing social and economic conditions.

The value of Bourn and Wint's study is that it raises important questions about the process of agricultural intensification by showing the existence of strong associations between the expansion of livestock raising and increasing population densities. Their results are a welcome alternative to the neo-Malthusian view of population growth and agricultural decline. In contrast to many doomsday scenarios, their study indicates that Africa's farmers and herders are successfully adapting their agricultural and pastoral systems to changing environmental and demographic conditions. The expansion of livestock raising in areas where one expects to find it declining suggests that much more research is needed to understand the dynamics of livestock raising in Africa today.

♦♦♦

Camilla Toulmin

I enjoyed reading this paper. Starting from the conclusions, it is clear that data on the incidence and rate of environmental degradation and rehabilitation in dryland Africa are very poor. This explains the marked contradiction between the alarmist picture and predictions painted by global analysis and much more positive assessments derived from local level research. The fact is, we do not really know what is happening. Many statements and programmes are based on statistics of very poor quality, which have been discredited by informed opinion. However, the figures that do exist tend to be grasped with great eagerness, because of our obsession with quantification, and confirmed by roadside judgements about land degradation as officials travel through the countryside in the dry season, when the soils and vegetation are looking their worst. Evidence is used highly selectively to support a pre-existing view. People frequently cannot see or interpret what is before their eyes. It is much easier to think of catastrophic terms, of inexorable disaster as the sands shift and swallow up fertile land, houses, roads, trees, and whole villages. It makes for much more exciting photographs too. The eyes of a journalist start glazing as soon as you say `well...., it's not quite like that and it all depends'.

Bourn and Wint provide us with some useful cross-cutting data, which demonstrate clearly the linkages between people, cultivation, levels of settlement, and livestock holdings. The evidence would seem, at first sight, to be at odds with an intuitive vision of how things ought to be - a vision in which we assume that most livestock are kept far from cultivated areas, to make best use of grazing and avoid risks of crop damage. However, for those of us who did their field work amongst cattle-rich settled farmers, the data confirms the great importance of livestock-crop linkages: manure, traction for ploughing, milk to supplement grain stores, and animals for selling when cash is needed for various investments (Toulmin 1992). It also makes clear that several factors are needed for livestock production, amongst which are fodder resources and labour. Limited fodder resources available in and around farming communities can be stretched through careful management and by supplementation and present less of a constraint than might be thought.

Bourn and Wint's analysis throws up a number of questions. What has happened, for example, to the mobile pastoral people and herds we would have expected to find in the arid zones? Are there really so few of them? Have there always been so few, or has there been such a substantial shift of animals from transhumant systems into more settled patterns of production? The data suggest that there are very few animals kept within highly mobile systems and hence the arguments marshalled in favour of retaining and supporting more opportunistic patterns of grazing are of very limited overall importance.

The authors also rightly pose the question - if processes of adaptation and change are occurring within these systems as they encounter new constraints and stresses, what, if anything, should outsiders (researchers, development agencies *etc*.) be doing to help this along? Do we have a useful role to play, and if so what? Many of the papers presented at the recent Symposium on Farming Systems Research (Montpellier, November 1994) raise the same questions. Having recognised the vitality and dynamism of local practice, how can research and development activity be re-oriented towards supporting rather than supplanting this? Can researchers turn themselves into effective `facilitators' and how many facilitators do we really need? At the Scottish Wildlife and Countryside Link meeting in Perth (November 1994) it was admitted that the best thing outsiders could do would be to provide comprehensible information to community groups about the range of funding sources now available, and guidance in where to get the forms and how to fill them out.

It is a pity we do not have data on livestock, cultivation and settlement over time, which would allow us to understand the dynamics of change in different settings. However, Bourn and Wint give us a base from which to re-assess conditions in the future.

♦♦♦

M. Norton-Griffiths

Bourn and Wint's paper is a valuable contribution to the debate on the intensification of livestock and agricultural production in sub-Saharan Africa. Of particular interest are the clear demonstrations that (1) livestock production is an integral part of agricultural production and not something separate and apart; that (2) livestock production intensifies along with agricultural production; and that (3) both livestock and agricultural production intensify with population density. Their discussion also has significance for development planning, for it suggests the futility of addressing livestock development independently from the broader issues of agricultural and land use development.

Bourn and Wint's data span half a continent, yet their broad conclusions are supported by more local studies. Working in Machakos district, Kenya, Mary Tiffen and her colleagues show clearly that below a certain critical density the population is trapped into subsistence production with neither the capital nor the labour to manage land effectively or to progress economically and socially. At the national level, also in Kenya (table 1), livestock production is clearly linked to intensive agriculture.

Table 1. Population, cultivation, livestock and production in Kenya[1]

Zone[2]		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Climate		Per humid	Humid	Sub-humid	Transitional	Semi-arid	Arid
Rainfall	mm	> 2000	1600	1400	700	600	< 400
% Kenya		< 1	4	12	16	26	42
Population	km^{-2}	29.8	314.0	187.2	58.5	17.9	3.7
	%	< 1	23	46	19	9	3
Crops[3]	ha km^{-2}	17.1	49.9	36.6	20.7	2.9	
	%	< 1	17	41	34	8	< 1
% Crop production[4]		< 1	22	40	31	7	<1
Livestock[5]	km^{-2}	33.8	146.5	122.6	128.7	90.7	22.9
		< 1	7	20	28	32	13
% Livestock prodn[6]		< 1	21	38	33	7	1

Notes:
(1) Source: Norton-Griffiths and Southey (1993) The opportunity costs of biodiversity conservation: a case study of Kenya. CSERGE Working Paper GEC 93-21. Centre for Social and Economic Research on the Global Environment, University College London & University of East Anglia. 49pp.
(2) The zones of land potential used by the Ministry of Finance and Planning in Kenya are equivalent to climatic zones.
(3) Proportion of all actively cultivated land and recent fallow.
(4) Proportion of total gross revenues from all agricultural production.
(5) Cattle + (smallstock/10)
(6) Proportion of total gross revenues from livestock production - including the value of subsistence production.

The semi-arid and arid parts of Kenya cover 68% of the country and hold 12% of the population, but the 45% of the national livestock herd living in these areas produces a miserly 8% of total livestock revenue. The Kenya dataset does not show the sharp decrease of livestock with high rainfall (compare table 1 to figure 4 in Bourn and Wint's paper), possibly because human population densities are higher. However, the Kenyan data suggest both livestock and people are excluded at high intensities of cultivation (table 2).

Table 2. Cultivation, Population and Livestock Densities in the Kenyan highlands (zones 1-4)[1]

% Active Cultivation	Population (km^{-2})	Livestock[2] (km^{-2})
0.0	8.8	48.5
5.0	61.8	61.9
15.0	114.1	77.7
25.0	141.4	80.1
35.0	193.4	76.6
45.0	223.2	66.6
55.0	253.7	62.9
65.0	182.2	53.5
> 75.0	148.5	39.9

Notes:
(1) Data from aerial point sample surveys in Kenya (see Norton-Griffiths, M. (1988) Aerial point sampling for land use surveys. *Journal of Biogeography* 15: 149-156).
(2) Cattle + (small stock/10)

Livestock densities in Kenya are clearly higher than those reported by Bourn and Wint, possibly because of the relative fertility of the highland soils in Kenya where most livestock are found. In the Bourn and Wint dataset, the Ethiopian highlands also contain relatively recent, fertile soils compared to other areas in the Sahel, and it would be interesting to test this hypothesis by including a dummy variable in their regression analyses representing landscape age.

Bourn and Wint also contribute usefully to the debate on wildlife and livestock production, for it really is now time to dispense with the romantic notion that wildlife and livestock production somehow co-exist. Wildlife increase vastly the costs of livestock production: wildlife compete for grazing, they spread disease, they eat livestock and people, and are generally a nuisance. Livestock producers have to undertake all sorts of defensive expenditures against them (compare the simple stock fence of a pastoralist in the ferlo of Senegal with the massive thorn boma of the Maasai). The livestock producer has two strategies towards wildlife. In the long term he can eradicate wildlife through a process of gradual habitat modification. In the short term, all he can do is to take avoiding action to keep out of their way. My own data from aerial surveys indicates the extraordinary extent to which pastoralists go to avoid contact with wildlife. Covering some 500,000 km^2 of open rangelands in Sudan, Kenya and Tanzania, the data show that the 25% of the surveyed area which contained active pastoral settlements held 66% of all livestock but only 3% of all wildlife. It would be interesting to see if the Bourn and Wint dataset supports a similar conclusion.

♦♦♦

Matthew Turner

The authors of this paper should be commended for their work in compiling the data described. Such data are needed to address a number of important questions including the effects of population growth on the `intensity' of agricultural production. However, I would urge the authors to use more contextual information about the production systems subsumed within their sampling grids, and to be more reticent in inferring the validation of a historical process (the Boserup hypothesis) from spatial correlations.

The authors found that the relative importance of the arid and semi-arid zones to livestock production was lower than previously estimated. This finding provides regional confirmation of more local observations in West Africa on the movement of animals and herders south during the 1980s. However, the extent of the decline in importance of the arid and semi-arid zones may be overestimated by this database. Most of the aerial surveys of these dryer zones were conducted during the early 1980s when livestock populations underwent drastic declines, while the National Livestock Survey in Nigeria (which included more humid zones) was conducted in 1992. The authors' conclusions regarding the importance of livestock movement should also be interpreted with caution since a major objective for many of these surveys was to estimate regional livestock densities, and the surveys were timed so as to limit or control for seasonal fluctuations in livestock density. The two survey areas that I am familiar with, the Inland Niger Delta and the Gourma regions of Mali, experience drastic swings in livestock densities in normal years. The limited degree of seasonality in Bourn and Wint's data is the result of either surveys being conducted during abnormally poor years (1984) or from the timing of survey flights (many herds remain on the Delta floodplain through June).

The study areas included in the database stretch from what many would view as true desert (<100 mm annual rainfall) to the humid tropics. Therefore, over a certain range of the data, human occupation, potential productivity (*e.g*. `carrying capacity'), and livestock populations will be highly autocorrelated and regression analysis will not shed light on underlying relationships. In other words, to compare these variables in the moist savannas of Nigeria and the Red Sea Province in Sudan tells us very little about whether there is more than a simple correlative (rather than a process-related) linkage between human and livestock population densities. Since the regression analyses were performed over such a wide range of production potentials, it is difficult to interpret the statistically significant relationships between livestock and human occupation densities. Would the relationship remain highly statistically significant once the low productive areas of say less than 400 mm a year were removed?

In order to evaluate any causal relation between human and livestock population densities, I would suggest that the data be analysed within more homogeneous agro-ecological and production zones. At the microscale, it is not surprising that livestock are closely associated with human habitations. Humans are the owners and managers of livestock. Therefore, animals will most often be found within 5-7 km (grazing radius) of some form of human habitation (village, pastoralist camp *etc*.) which may or may not be identifiable from the air. In this regard, it would aid the readers' interpretation of the results if the dimensions of the spatial sampling units were provided for each of the aerial surveys included in the data.

The Boserupian hypothesis predicts that population growth will lead to more intensive forms of production (*i.e*. greater inputs leading to greater output per unit of land). Historical case studies of `autonomous intensification' have provided an important counterweight to the neo-malthusian vision that resource availability determines human population levels. There are, however, several problems regarding the authors' interpretation of their data as evidence of autonomous intensification. The first has been described above; over a significant range of their data, the Boserupian independent variable, human population, is highly correlated with the Malthusian variable, productive potential or `carrying capacity'. Another problem arises from Bourn and Wint's working definition of land-use intensity as the fraction of land cultivated, which is not a dependent variable of concern for the Boserupian hypothesis which addresses the relativity between greater inputs and outputs per unit land area. neo-Malthusians would find the correlation between human settlement density and livestock populations perfectly consistent with their vision of the evolution of these systems.

♦♦♦

Pierre Hiernaux

We should be grateful to the authors for the invaluable database they have built over the last 15 years on rural land use in sub-Saharan Africa in general, and on livestock population and production in particular. Analysis of this database should help us interpret agricultural statistics for sub-Saharan Africa which are particularly poor for livestock. This is important because poor statistics may bias predictions and misguide policy formulation.

I would like to stress the importance of seasonality for the agricultural production systems covered in Bourn and Wint's surveys. The precise dates and geographical locations of the surveys used by the authors have almost certainly influenced the correlations and trends they describe. Consider, for example, the relative importance of large wetlands like the Gezira or the Inland Delta of the Niger River, for the regions surveyed in the arid and semi-arid zones. The ecological peculiarities of such areas are reflected in all aspects of land use and livestock production. Wetlands such as the Inland Delta of Niger are complementary to surrounding upland areas, seasonally providing abundant forage and concentrating livestock in ways which cannot be predicted from rainfall patterns. These large wetlands also influence livestock numbers and movement in surrounding regions, as it can be observed on the figures 8 and 9 for the south-eastern shore of Lake Tchad or the Niger river valley. Combined with particular survey dates, wetlands may have influenced some of the trends presented and particularly the seasonal distribution of livestock. These factors may have obscured the extent of the wet season transhumance between the semi-arid and arid zones and resulted in an overestimation of livestock density (on a yearly basis) in the semi-arid zone.

Although I do not dispute the correlation established between the livestock distribution and percentage area cropped, density of rural settlement and rainfall, more emphasis should have been placed on the possible effects of collinearity between the three explanatory variables. The same trends could result from different processes depending on the ecozone. In the dry season, for example, livestock may be concentrated in areas close to settlement because of the relative proximity to water points. Livestock concentrations at the same season in densely populated, sub-humid areas are more likely to be related to post-harvest crop residue grazing and to the preference given to fields close to villages for livestock night camping or corralling, when not stall fed in the villages.

Agricultural expansion, *i.e*. the increase in the proportion of area cropped (which should, where possible, be calculated as a percentage of arable land rather than total land), should be clearly distinguished from the intensification of agricultural production. Intensification implies increasing expenditure on inputs per unit area cultivated to attain higher productivity per unit area. If agricultural expansion has occurred throughout sub-Saharan Africa, following the increase of rural human population, evidence for intensification is less common. Reportedly, cereal productivity per hectare has decreased consistently over the last 20 years in the Sahel. Only intensification of agricultural production, and not simple expansion of the area cropped, supports the Boserup hypothesis. I do not believe that intensification would be an inevitable consequence of population growth. In some regions, such as the Gourma, systems of production have not intensified. Indeed, production has not even expanded to keep pace with population growth, and populations have become progressively marginalised or have migrated. Intensification should only develop where increased inputs are accessible and their use is profitable. This could be the case in the semi-arid and sub-humid zones of northern Nigeria as shown by the data presented on the spread of livestock ploughing and fattening (figures 10 and 11). However, it is risky to try and predict temporal changes on the basis spatial comparisons, unless the processes are proved to be universal, which is unlikely across such a range of contrasted environments.

I would like to conclude with some final questions and observations for the authors:

- It would be useful to give an indication of the spatial resolution of the grid of geo-referenced points, and possibly the rate of sampling used to give this point estimate (area surveyed *vs*. area of the unit of resolution).

- In some regions towns are centres for the spread of more intensive husbandry practice. Is there any evidence of the influence of urban centres on livestock distribution?

- Regarding the relationship between livestock distribution and habitation density, it would be useful to know what fraction of the livestock statistics consisted of `concealed village livestock' as they are by origin linearly related to roof-top counts.

♦♦♦

Patrick Duncan

Bourn and Wint address an important issue, in terms of rangelands science and the economic development of Africa. Livestock densities at the regional scale vary across the continent by about two orders of magnitude and it is surprising that the causes of these variations are not well understood, given the need for policy makers and farmers alike to know if the principal causes are ecological and/or socio-economic.

Early papers by Coe *et al*. (1976), and Bourn (1978) proved useful as they demonstrated the value of approaching this issue in a comparative way using statistical techniques at a regional level. But the data they used were limited, either in extent or in accuracy. These problems are currently being solved, at least to some extent (*e.g*. Oesterheld *et al*. 1992, Fritz and Duncan 1994), and this paper by Bourn and Wint provides the best analysis so far for livestock. The authors have a detailed personal knowledge of the subject from field surveys and aerial censuses, and include both ecological and socio-economic variables in a multivariate analysis of data from a very large area. Their major conclusions are plausible (a correlation, probably log-linear, between livestock and human densities was also found in a small analysis of the national livestock census of Senegal, at the level of the country's 27 administrative regions, Duncan 1980).

The multivariate analysis, which was conducted to elucidate the effects of three `explanatory' variables of livestock biomasses was, however, not easy to follow. This is clearly a difficult exercise (and these comments by a field ecologist may well be demolished by a professional statistician). First, I am not sure why the seven thousand points were considered statistically independent. If they are not, then their number could lead to spurious significance levels. Second, the nature of the explanatory variables (cultivation, rainfall and habitation density) poses two problems. The variables are presumably interrelated, so the regression coefficients which link them to livestock biomass are unstable and, further, the relations of these explanatory variables with livestock biomass appear non-linear. The stepwise regression model assumes that the relationships are linear.

If this technique is to be useful in partitioning the variance in livestock biomass between these explanatory variables, then solutions to these problems need to be found. The answers may well be provided in the major report from which this paper is extracted, in any case it will be of interest to the readers of the Network Papers to know how these modelling problems can be dealt with.

Issues of modelling aside, I believe that this paper is important, and will prove to be the first of a generation which, by looking simultaneously at ecological and socio-economic variables, will take comparative, regional analyses further; and will provide scientists and decision-makers with more reliable models of rangeland systems.

♦♦♦

Len Reynolds

The paper discusses the distribution of domestic livestock, both sedentary and pastoral across a broad swathe of Africa, before focusing on Nigeria. The key variables used to explain livestock distribution are the percentage of land under cultivation, human density and rainfall. The authors have prepared a paper that should stimulate discussion, and suggest areas where further research should be focused.

The paper differentiates between the effects of percentage land cultivated and habitation density. The relationship between habitation (*i.e.* roof-top count) and household group is not clear - how many people per roof-top, or how many roof-tops per family group? It is also unclear how the conclusions in the paper with respect to percentage cultivation and habitation density would be reconciled on the ground, unless cultivated areas are located considerable distances from habitation (unlikely given the cell size for analysis), the area cultivated per habitation varies, or the number of habitations per household varied across and within the survey sites. Area cultivated/household is expected to decrease at high population densities, and on land of high agricultural potential. Using the equations derived by the authors, livestock biomass density rises from 7.2 TLU/sq. km at 10% cultivation to 24.4 TLU/sq. km at 90% cultivation, which is a reasonable fit with the observations. However, the second predictive equation gives 8.9 TLU/sq. km with a habitation density of 10 houses/sq. km, rising to 25.5 and 38.4 TLU/sq. km at 60 and 120 houses/sq. km respectively. Combining these two predictions would indicate (for example) that at 90% cultivation and 60 houses/sq. km, we should find approximately 25 TLU/sq. km, giving each household 1.5 ha under cultivation and slightly over 0.4 TLU. At a lower habitation density of 10 houses/sq. km and at 15% cultivation density the equations predict around 9 TLU/sq. km - again the area cultivated is 1.5 ha/habitation but now with 0.9 TLU/habitation.

The third predictive equation is based on rainfall and gives 3.7 TLU/sq. km at 100 mm rainfall, rising to 9.2 TLU/sq. km at 800 mm, before slowly decreasing so that at 2000 mm there are still 8.1 TLU/sq. km. These figures for livestock density based on rainfall are so different from the previous two sets of predictions, and from the observations plotted in figure 4 as to be of little value.

In arid and semi-arid areas there is considerable variation in rainfall between years, although less so in humid and sub-humid zones. The studies were undertaken at different times, and it is not clear in the text whether rainfall figures used in the analysis relate specifically to the year when the studies occurred or whether the rainfall values taken were means across a number of years[2].

The statement that `a high proportion of animals were resident throughout the year' contradicts the visual evidence presented in figures 8 and 9, which show that livestock densities were higher in the wet season than the dry season. Rains come at slightly different times at different latitudes, the north receiving rain later than the south. While it is possible that livestock movements relate to the timing of rainfall across areas within the same annual precipitation band, it would require longer distance movement than the authors suggest.

In principle habitation density and cultivation density should not display seasonality. However, the fact that habitation is the primary factor in the wet season, accounting for 54% of the variance in livestock biomass density, but is only a secondary factor accounting for 9% in the dry season, indicates that there are noticeable seasonal differences in livestock distribution. There is evidence that pastoralism in Nigeria has declined, while settled mixed farming has expanded. One might speculate on the reason for the observed differences in livestock distribution. Socio-economic rather than climatic factors may be an explanation. Possibly, in the wet season adult labour is required for cultivation, and younger children can herd animals in the vicinity of the farm, but after harvest adult labour is available to take livestock further afield. Hence, the demands of mixed farming, rather than purely pastoral concerns may now determine livestock distribution.

Livestock biomass density (TLU/sq. km) rises sharply up to 700 mm rainfall (figure 5) and then declines. As discussed in an earlier report on Nigeria by the same authors, the contribution of cattle to the total increases up to 600 mm rainfall and then declines, with the contribution of small ruminants showing movements an opposite trend. There was little seasonal difference in small ruminant density within any rainfall band, but within the 750-1250 mm rainfall range cattle density was higher in the wet season than dry season. Cattle were moving; small ruminants were stationary. This again suggests a settled community, from which the cattle can be taken in the dry season.

♦♦♦

Jan Slingenbergh

2Rainfall distribution will certainly affect forage production, particularly between areas with unimodal and bimodal patterns, by affecting the length of the growing season. However, this should not be a factor for the Nigerian data.

Bourn and Wint's paper is invaluable, and the authors should be commended on their interpretation of a massive amount of data. One issue that deserves more detailed consideration, however, is the effect of tsetse infestation on livestock distribution. More specifically, I would like to question the authors' assumption that autonomous trypanosomiasis control affirms the Boserup hypothesis on the intensification of agricultural production. Passive tsetse control as well as (major) active tsetse control schemes have probably changed the landscape in Nigeria. A reduced trypanosomiasis risk influences ruminant livestock distributions. In the Nigerian scenario, this has probably furthered the shift from pastoral to agro-pastoral and mixed farming systems. It is likely that tsetse control in the dry sub-humid zone (length of growing period 120-179 days) provided the option to keep cattle throughout the year, thus offering the means to advance the integration of livestock and crop production.

There are, however, unknown factors. Crucially important is the information on changes in trypanosomiasis risk, both spatial and temporal. Today, bovine trypanosomiasis persists as a major animal health constraint over most of the tsetse-infested southern half of Nigeria; recent trypanosomiasis prevalence data compiled by Ilemobade (FAO, unpublished) suggest that over 9% of the cattle carry pathogenic trypanosomes (22,000 animals sampled, using routine and fairly insensitive parasitological techniques for diagnosis). In the tsetse-free northern half of the country, however, only 1% of the 19,000 cattle sampled tested positive. There is a fairly sharp boundary between the tsetse-free, dry sub-humid northern part of the country and the tsetse-infested, moist sub-humid (length of growing period 180-269 days). Equines are confined to the tsetse-free areas and so are the vast majority of the `village' cattle. As a consequence, the `ploughing line' roughly coincides with the tsetse demarcation line.

It would appear that the `autonomous trypanosomiasis control' has come to a stand-still. Tsetse is now confined to areas where flies are less vulnerable to attack, although in this respect it is important to differentiate between riverine and savanna tsetse. *G. morsitans* flies, more dependent on the presence of game animals and woodlands, has disappeared over a much wider area than the riverine *G. tachinoides*. The latter species became retracted largely through active control in the form of the removal of the riparian vegetation and insecticide campaigns. However, northward-extending linear fly infestations along water courses still persist today. The indications are that woody vegetation along rivers remains relatively untouched, while other woodland vegetation is more readily sacrificed for fuelwood collection, charcoal burning, expanded cropping and other purposes.

It is therefore unlikely that the diminishing trypanosomiasis risk proceeds at the same pace as the growing demand for more productive mixed farming. Bourn and Wint's dataset shows that in the tsetse-infested areas of moist sub-humid Nigeria, village cattle are virtually absent despite high population density and high land use and cereal cropping intensities. In otherwise identical agro-ecological circumstances it is the presence of tsetse alone that prohibits the introduction of cattle on a more permanent basis. It could be speculated that the persisting tsetse problem in the moist sub-humid Middle Belt of Nigeria goes against the Boserup hypothesis on agricultural intensification! In any case, it is difficult to produce convincing generalisations with regard to the occurrence and effects of autonomous trypanosomiasis control.

♦♦♦

REPLY TO COMMENTS

David Bourn and William Wint

General Points of Clarification

The graphs in our paper represent grouped or `binned' data, where the plotted y-values are means for sequential ranges of x-values. The width of the x-value `bins' has been adjusted so that each contains at least 150 points. In figure 3, for example, there are some 167 points (from a total of 3,666) contributing to the mean TLU value for settlement densities between 60 and 140 roof-tops per sq. km.

This form of presentation is intended to draw attention to general trends, and should not be used for direct interpolation of either variable. In reality, the raw data are continuous and have a much more scattered distribution than indicated by plots of their mean values. A measure of this variability is given by the vertical bars representing two standard errors. In mathematical terms, the datasets are best described by equations given beneath each figure, which were determined by statistical least squares analysis of all points using various standard transformations.

Other points which require clarification are:

- Rainfall figures used in the analysis are mean annual values *(Reynolds)*.
- The size and date (season) of each survey is given in table 1 *(Tiffen)*.
- Sample frames used for systematic aerial surveys of each area were based on either a 10×10 km, or 20×20 km grid, which gave sample intensities of between 5 and 10% *(Hiernaux and Turner)*.
- More detailed accounts of the various livestock production systems within the areas surveyed are to be found in the references cited in table 1 *(Bassett, Sumberg and Turner)*.

Other points of discussion

Duncan, Reynolds, Sumberg and Turner

With regard to our interpretation of figure 5, we stand by our statement that `At the macro level this implies that a high proportion of animals are resident, or at least remain within the same rainfall zone throughout the year, and that long distance seasonal movements are relatively uncommon'(p. 9). Local movements over central Nigeria, referred to by Reynolds, do not invalidate our observation. We accept, however, that seasonal variations are likely to be obscured by combining data collected from various localities over a period of years.

Concerning the seasonal differences in livestock density in various agro-ecological zones indicated in table 2, and in response to Sumberg's query about where animals go to in the dry season, it is perhaps worth pointing out that the overall density of livestock biomass was found to be some 8% lower during the dry season than during the wet. Leaving aside seasonal patterns of births and deaths, which might well contribute to cyclical fluctuation in livestock numbers, with the uncertainties inherent in sample surveys conducted over a period of more than a decade, we consider such a disparity to be of minor consequence.

We acknowledge that potential collinearity between some of the independent variables means that interpretation of the multiple stepwise regression analysis should be treated with some caution. However, we wish to point out that linkages between many of the variables are far from obvious and straightforward, as indicated by the relationship between land use intensity and the density of human settlement (supplementary figure 1 below), and the density of livestock biomass and percentage grassland (supplementary figure 2). Collinearity is not, therefore, considered to be a major problem, and it does not detract from the major thrust of our argument. We also confirm that the relationships between livestock and cultivation, and livestock and human habitation, remain statistically significant, even when less productive areas with less than 400 mm per year are excluded from the analysis.

Figure 1. Land Use Intensity and the Density of Rural Settlement

The equations accompanying each figure are mathematical descriptions of the relationships between variables within the assembled dataset. As we have pointed out, these relationships should not be taken as proof of causality. Thus, for example, the close predictive link between livestock biomass and cultivation does not mean that cultivation attracts animals *per se*, but rather, that some property of those areas with high levels of cultivation is associated with high animals densities.

These properties may include: access to marginal fodder resources associated with cultivation, such as crop residues, and fallow land; proximity to markets and services; or, particularly in more arid regions, the availability of water.

Figure 2. Livestock Biomass: % Grassland

Whatever the precise causal relationships may be, and these are likely to vary with both time and place, the clear indication is that more animals tend to be found in areas where there is more cultivation. This is true for all but the wettest rainfall zone, where the extent of natural grazing was the closest correlate of livestock biomass, and for all livestock species except camels. This suggests that when rainfall is factored out of the analysis (by examining the data for the four rainfall bands separately) some correlate of the presence of people and human activity is still the best predictor of livestock numbers.

Hiernaux

We wish to stress that the various relationships described in our paper hold for both directly observed and indirectly determined elements of livestock populations. Such linkages cannot, therefore be ascribed to some artefact of the enumeration technique, which is only partially dependant on roof-top counts.

The distinction between pastoral and non-pastoral livestock is a problematic issue, both on the ground and from the air. Reality is a continuum from one extreme to another, with a range of transitional states in between. With that proviso, and on the assumption that most livestock directly visible from the air and away from the immediate vicinity of villages are under some form of more extensive pastoral management, our findings indicate that between 60 and 70% of overall livestock biomass fall within this category, compared with 30-40% found in more confined, village based production systems. These overall proportions obviously mask considerable variation from zone to zone, ranging from the purely pastoral to the exclusively village-based.

As Hiernaux suggests, the relatively high densities of livestock in the arid zone compared with Jahnke's figures may be due, in part, to the selection of survey sites such as the Inland Delta in Mali, which is known for its livestock concentration. However, in the authors' opinion such foci are of limited extent, compared with the rest of arid zone surveyed, and are partly offset by other sites, such as Red Sea Province in Sudan, with very low livestock densities.

The resolution of our database is too course to provide direct evidence for the influence of urban centres on livestock distribution. Nevertheless, we would expect to find livestock concentrated in peri-urban environment because towns and cities of the West African savannah are generally surrounded by extensive areas of cultivation. Ground surveys of 24 major towns and cities in Nigeria, carried out as part of the National Livestock Resources Survey (FGN/RIM, 1992), clearly demonstrated the existence of substantial livestock populations within urban areas.

Duncan and Norton-Griffiths

Livestock and wildlife densities certainly seem to be appreciably higher in East Africa, and our surveys indicate that wildlife have been virtually eliminated from much of West Africa. The contrasts between east and west are tantalising, and a more thorough investigation of comparable datasets from across the continent, incorporating livestock, wildlife, people, land use, soil fertility and climatic factors, including seasonality, would certainly seem to be well justified.

Slingenbergh and Sumberg

With regard the declining importance of tsetse and trypanosomiasis, this is clearly a complex interdisciplinary issue, which can be viewed from various standpoints. In arguing the case for the autonomous control of tsetse and trypanosomiasis, we do not wish to deny the potential value of organised vector and disease control programmes. Rather, we choose to interpret our findings in the more general context of on-going environmental change, and to stress the significance of multiple human impacts on the environment as key determinants of disease epidemiology.

Hunting and deforestation are autonomous human activities which have resulted in the virtual elimination of wildlife reservoirs of trypanosomiasis, and greatly reduced the extent of tsetse habitat over large tracts of Africa. The cumulative impact of human population growth and agricultural expansion has, in many areas tipped the epidemiological balance away from wildlife towards a disease transmission cycle increasingly focused on domestic livestock. Under these circumstances natural selection will favour development of less virulent and pathogenic forms of the disease, leading to the ultimate coexistence of both parasite and `new' domestic host.

Despite the incidence of trypanosomiasis reported by Ilemobade (quoted by Slingenbergh) and the persistent survival of tsetse in shrinking habitats, we consider that the year-round presence of some 6.25 million head of cattle within the Nigerian sub-humid zone (45% of the national herd), is strong evidence for evolutionary adaptation and epidemiological transition. Otherwise, how can such a large numbers of supposedly trypano-susceptible cattle survive? From personal field experience, we would, therefore, strongly contest Slingenbergh's suggestion that `autonomous trypanosomiasis control has come to a stand-still'. It most certainly has not.

What we are witnessing in Nigeria (and, one suspects, many other West African countries) is a progressive southward dispersal of zebu cattle, moving into former areas of wilderness and tsetse infestation. In our view, it is only a question of time before zebu become established throughout the sub-humid savannah regions of West Africa. This process obviously needs to be monitored, and deserves the attention of national research institutes and international development agencies. Readers wishing to explore this subject further are referred to the works of Ford (1971), Kjekshus (1977), Putt *et al*. (1980), Bourn (1983) and Jordan (1986), quoted in our original paper.

Acknowledgements

We would like to thank all those who have taken the time and effort to comment on our discussion paper. Their responses have been both challenging and informative. We are also pleased to acknowledge the support of our sponsors: OXFAM and the British Government's Overseas Development Administration. Collectively, we hope to have stimulated a wider interest in the role of livestock in agricultural development, and to have demonstrated the importance of monitoring the processes of environmental change.

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